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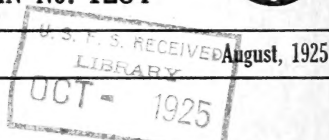


In Cooperation with the  
Kansas and Missouri Agricultural Experiment Stations and  
the Brooklyn Botanic Garden



DEPARTMENT BULLETIN No. 1284

Washington, D. C.



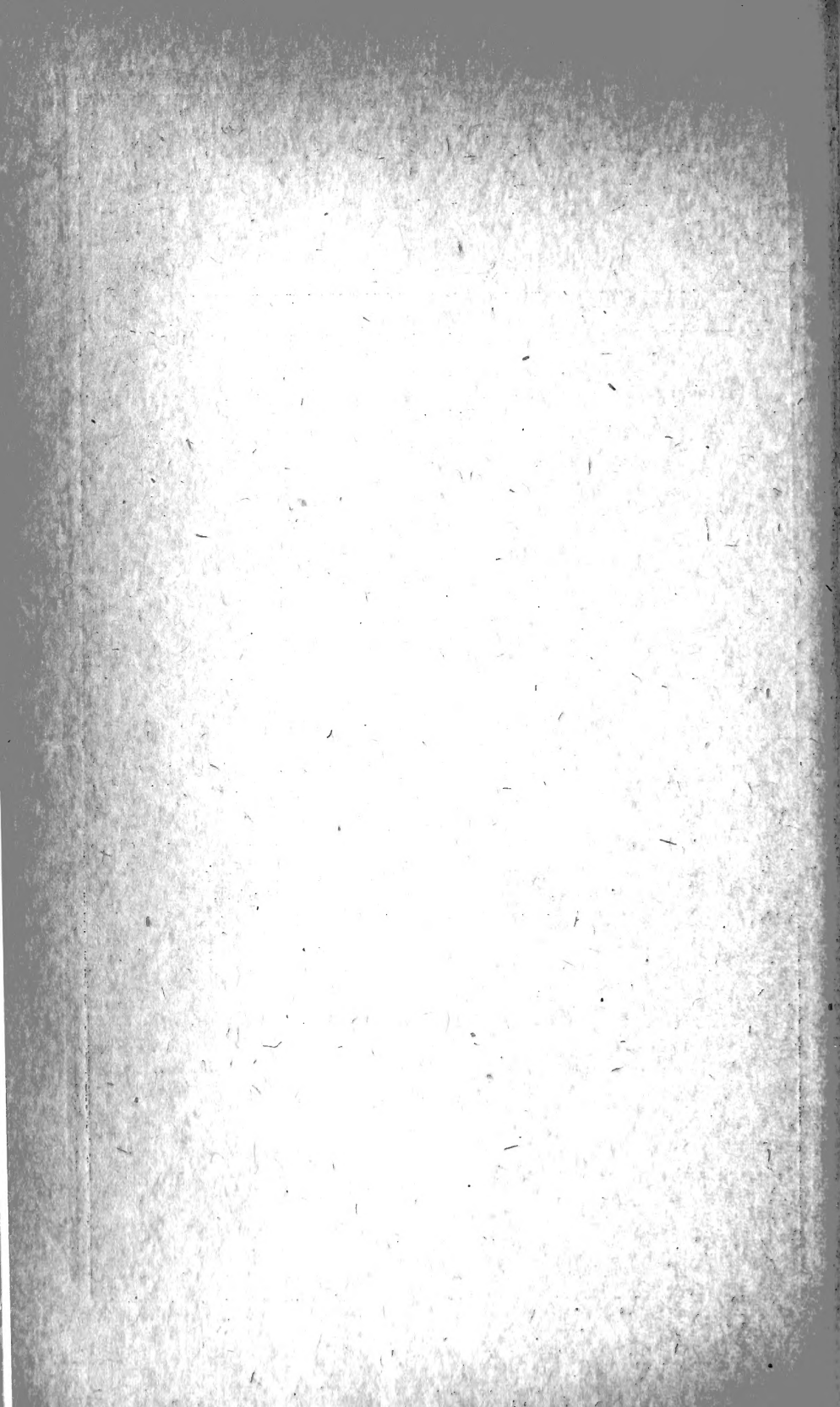
## SORGHUM SMUTS AND VARIETAL RESISTANCE IN SORGHUMS

By

GEORGE M. REED, Curator of Plant Pathology, Brooklyn Botanic Garden, formerly Pathologist in Charge  
of Cereal-Smut Investigations, Office of Cereal Investigations, Bureau of Plant Industry, and  
LEO E. MELCHERS, Plant Pathologist, Kansas Agricultural Experiment Station, and  
Agent, Office of Cereal Investigations, Bureau of Plant Industry

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August, 1925

### SORGHUM SMUTS AND VARIETAL RESISTANCE IN SORGHUMS<sup>1</sup>

By GEORGE M. REED, *Curator of Plant Pathology, Brooklyn Botanic Garden, formerly Pathologist in Charge of Cereal-Smut Investigations, Office of Cereal Investigations, Bureau of Plant Industry, and LEO E. MELCHERS, Plant Pathologist, Kansas Agricultural Experiment Station, and Agent, Office of Cereal Investigations, Bureau of Plant Industry*

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#### INTRODUCTION

The sorghums now occupy an important place among American farm crops. They have been found well adapted to the southern half of the Great Plains area, which includes the western portions of Kansas, Oklahoma, and Texas and the eastern portions of Colorado and New Mexico, where crop production is very largely governed by the quantity and distribution of the annual rainfall. In this section, under the conditions of low annual precipitation and its uneven

<sup>1</sup> The preparation of the manuscript of this bulletin was finished by the writers on August 31, 1923, but publication has been unavoidably delayed.

The senior writer is specially indebted to Director F. B. Mumford, of the Missouri Agricultural Experiment Station, for his courtesy in permitting the use of the data obtained at that station in this bulletin. Special acknowledgments are due to Charles R. Hursh, Fred N. Briggs, Charles H. Philpott, and Miss Jessie A. Cline for assistance in the investigations at the Missouri Agricultural Experiment Station, and to Ivan A. White and Charles O. Johnston for assistance at the Kansas Agricultural Experiment Station. Alden A. Potter, then assistant pathologist in the Office of Cereal Investigations, conducted the experiments at Amarillo, Tex., from 1916 to 1918 and also assisted the junior writer at Manhattan, Kans., in the same years. Miss Marion A. Griffiths gave valuable aid at Arlington Experiment Farm in 1919 and 1920, and Miss Naomi Howells assisted in the investigations at Brooklyn in 1921. The writers also are greatly indebted to John F. Ross, formerly superintendent of the Cereal Field Station, Amarillo, Tex., for sowing and caring for the experimental plats at that station.

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distribution, the sorghums are able to produce larger yields and with greater certainty than corn, wheat, and other crops. Consequently, the total acreage devoted to sorghums has greatly increased during the last few years. In 1903 approximately 2,000,000 acres were sown to this crop, and in 1918 more than 6,000,000 acres. The acreage in 1919 showed a decrease from that of 1918, yet more than 5,000,000 acres were grown (100).<sup>2</sup> The estimated area in grain sorghums in 1922 was 5,057,000 acres.

The sorghums have long been under cultivation in various parts of the Old World, and their great diversity is no doubt due to their utilization by man in widely separated regions. In India (63) sorghums occupy third place among cultivated crops, covering an area of 21,000,000 acres. In the Bombay Presidency the crop ranks first, more than 8,000,000 acres being grown annually, constituting more than one-third of the area devoted to the cultivation of grains. In parts of northern China (5) the kaoliangs constitute the chief crop of the inhabitants. The kafirs, sorgos, and durras are extensively cultivated in various sections of Africa. Broomcorn is an important agricultural product of Italy and Hungary.

The sorghums are regarded as having been derived from the wild species *Holcus sorghum* L. (*Andropogon sorghum* (L.) Brot.) (47, 87, 118). The wild forms of the species, such as Sudan grass and Tunis grass, are distributed in central and southern Africa, Egypt, Madagascar, and neighboring islands. They are annual plants, without rootstocks, and are differentiated into a number of distinct races or subspecies. They readily hybridize with the cultivated sorghums. A closely related species is *Holcus halepensis* L. (*Andropogon halepensis* (L.) Brot.), which includes the perennial forms with rootstocks, such as Johnson grass and related forms. The various races or subspecies are widely distributed in southern Europe, northern Africa, and western Asia. Hybrids between Johnson grass and the sorghums have rarely been observed, and attempts to cross them artificially are only occasionally successful.

Sorghums, like other crops which are extensively cultivated, are subject to many diseases. The sorghum smuts, however, are generally recognized as the most destructive diseases of sorghum, and much attention has been given to them in order to determine their life histories and methods of controlling them.

### SMUTS ATTACKING SORGHUMS

The primary purpose of the investigations described in this bulletin was the determination of the behavior of the different varieties of cultivated sorghums with reference to their susceptibility or resistance to the covered kernel smut, *Sphacelotheca sorghi* (Link) Clinton, and the head smut, *Sorosporium reilianum* (Kühn) McAlpine. No extensive studies of this nature have been conducted, although mention has frequently been made of the occurrence of smut on broomcorn, sorgos, kafirs, durras, and kaoliangs. The absence of smut on milo and feterita has been noted frequently. If certain sorghums, such as milo and feterita, possess a marked degree of resistance to the smuts, they furnish a sound basis for conducting breeding experiments for the improvement of sorghums by combining

<sup>2</sup> The figures in italic within parentheses refer to the bibliography at the end of this bulletin.

the quality of smut resistance with desirable agronomic characters. Although covered kernel smut can be controlled by seed treatment, the methods involve considerable labor and expense. Head smut can not be controlled by seed treatment, but development of resistant varieties offers a possible solution of the problems presented.

#### COVERED KERNEL SMUT

The covered kernel smut, *Sphacelotheca sorghi* (Link) Clinton, was first described in 1825 from a specimen collected in Egypt by Link (68, p. 86), who called it *Sorisporium sorghi*. In 1846 Tulasne (112) transferred the fungus to the genus *Tilletia* as *Tilletia sorghi-vulgaris* Tul. Passerini (82) in 1873 described the same fungus under the name *Ustilago sorghi* Pass. Kühn (60) in 1874 determined from a study of the germination of the spores that the fungus properly belonged in the genus *Ustilago* instead of *Tilletia* and applied the name *Ustilago tulasnei* Kühn. Brefeld (13, p. 31-33) seems to have regarded *U. sorghi* Pass., and *U. tulasnei* Kühn as two different species, but this distinction has not been accepted generally. Clinton (22) in 1897, from a study of its mode of spore formation, transferred it to *Cintractia* as *Cintractia sorghi-vulgaris* (Tul.) Clinton, but in 1902 he (24) concluded that the fungus belonged more properly in the genus *Sphacelotheca* and named it *Sphacelotheca sorghi* (Link) Clinton.

The covered kernel smut unquestionably is the most widely distributed and destructive smut which attacks the sorghums and is probably to be found wherever sorghums are grown. Barber (8), Kulkarni (63), and Butler (21) record its prevalence in various parts of India. It is a destructive disease in Madras Presidency, Bombay Presidency, the Central Provinces, and Burma and also is present in the northern parts of India, as in Dehra Dun. Kulkarni states that this smut is much more prevalent in the varieties of the kharif crop than in those of the rabi crop. The kharif varieties constitute the monsoon crop, which is sown in June and July and harvested in October and November. It is grown during the wet season and consists largely of varieties of durra. The rabi, or winter crop, is sown in September and October and harvested in February and March. The rabi crop seems to consist very largely of varieties of shallu.

Ball (5) states that practically all seed lots of Chinese kaoliangs imported into the United States were contaminated with the spores of this smut, indicating its general prevalence in those parts of China where kaoliangs are grown. Thomas (109) and Bubák (17) have noted its occurrence in Mesopotamia, Briton-Jones (14) in Egypt, Busse (20) in Tanganyika Territory (formerly German East Africa), Snowden (105) in Uganda, Patouillard (84, 85) in Tunis, Evans (36) in South Africa, especially on kafirs, McAlpine (70) in Australia on broomcorn, Amber sorgo, and another sweet sorghum, and Hauman-Merck (44) and Hauman and Parodi (45) in Argentina. It has been commonly mentioned in published lists of smuts in Europe, as by Winter (120) in Germany, Schroeter (104) in Silesia, Lind (66) in Denmark, Lindau (67) in the mark of Brandenburg, Potebnia (88) in Russia, Bubák (18) in Bohemia, Malkoff (72) in Bulgaria, Prillieux (93) in France, Fragoso (39) in Spain, and Turconi (113) in Italy.

The first record of the occurrence of this smut in the United States was made in 1888 by Burrill (19), who noted the appearance of the smut in Illinois on broomcorn and sorghum. Webber (119) recorded it on "millo maize" from Nebraska in 1889, and in 1890 Failyer and Willard (38) recorded it on several imported varieties of sorghum grown for the first time at the Kansas Agricultural Experiment Station. Kellerman and Swingle (58) in 1890 gave a more complete account of the first occurrence of the smut in Kansas, stating that several of the sorghum varieties had been obtained through the United States consul at Calcutta, India, while others had been imported from Africa. In 1906 Clinton (26) recorded its occurrence in 13 States, as well as in Ontario, Canada, and in Jamaica and Cuba.

Covered kernel smut was recognized by Clinton (22) as an important disease of broomcorn in Illinois, and Güssow (43) called attention to its destructiveness on the same crop in Canada. It is particularly prevalent, however, in the sorghum belt of the southern Great Plains area, attacking sorgo, broomcorn, kafir, durra, kaoliang, Sudan grass, etc.

Doubtless most of the damage caused by the sorghum smuts is due to the covered kernel smut. Kulkarni (63) estimated that the damage to the sorghum crop in the Bombay Presidency is 10 per cent, amounting annually to about £1,350,000. Melchers (73) has estimated that the annual loss to kafir, broomcorn, and other sorghums in Kansas is at least \$400,000. Probably the annual loss in the entire United States amounts to \$3,000,000. The amount of damage varies greatly in different localities and in different seasons. It is not uncommon to find from 30 to 40 per cent of infection in some fields. Ordinarily, however, the percentage of infected plants is much smaller, and many fields may be entirely free from smut.

The damage is due to the destruction of the grain. The loss is complete in the sorghums used for grain only, and the value of sorghums used for forage is greatly decreased when the grain is destroyed, as smutted plants have only about half the feeding value of normal plants. Smutted broomcorn plants generally are a total loss, because the brush usually is of inferior quality, and the plants frequently have an excessive development of the thickened central axis and branches of unequal length. The smut spores also may be scattered over good brush in harvesting, discoloring it and thus lessening its value.

*Sphacelotheca sorghi* is a typical kernel smut, the individual ovaries of the flowers being involved and converted into false kernels or smut balls (Pl. I). Usually all the ovaries are transformed into the smut balls, but it is not uncommon to find normal kernels produced on infected heads. An infected sorghum plant is quite normal in size and general appearance, and the presence of the disease can be recognized only when the head emerges from the sheath. The glumes surrounding the flowers are essentially unchanged, retaining their normal size and color, although sometimes they have a purplish tinge.

The size of the smut balls varies considerably in different varieties. In some cases they remain small and concealed by the glumes. Usually, however, the ovary is greatly hypertrophied, giving rise to a conical or cylindrical structure 3 to 12 millimeters in length

and 2 to 4 millimeters in diameter (Pls. II and III). The wall of this structure consists of a rather thick grayish brown membrane, composed mainly of hyaline, oblong to subspherical fungous cells 7 to 9  $\mu$  in diameter. The wall incloses the smut spores which fill the interior and surround the central columella, consisting mainly of the remnants of fibrovascular bundles. The membrane breaks more or less irregularly when mechanically injured and allows the spores to escape. This commonly takes place in threshing operations and results in the contamination of the grain.

The spores, morphologically chlamydospores, are spherical or subspherical, rather thick walled, smooth, and 5 to 9  $\mu$  in diameter, averaging about 6  $\mu$ . In mass the spores are dark brown, but singly they are olive brown in color. They may retain their viability for a long period.

The germination of the spores has been described by Brefeld (12), Norton (80), Clinton (22), Kulkarni (63), Butler (21), and others. They germinate readily in water and in one type of germination give rise to a typical promycelium of three to four cells, which buds off sporidia laterally and from the apex. The sporidia are spindle shaped, 10 to 12.5 by 2 to 3  $\mu$ . Clamp connections and buckle joints occur. In the other type of germination the spore does not give rise to a typical promycelium, but a branching germ tube arises from the spore. Various intermediate types may occur. In various nutrient solutions a more vigorous germination takes place, giving rise to typical promycelia with sporidia, and the latter multiply rapidly by a process of budding.

Clinton (22) was one of the first investigators to demonstrate the probability of seedling infection by means of seed-borne spores. He planted inoculated seed as well as seed from a smutted crop and obtained a relatively high percentage of smutted plants. He also inoculated seedlings before they emerged from the soil and obtained a slight amount of infection. Kellerman (52, 54) inoculated sorgo and broomcorn seed with spores obtained from sorgo and obtained about 19 per cent of infection in the sorgo and 49 per cent in broomcorn. The significance of seed-borne spores in the development of covered kernel smut is amply proved by the work of Kulkarni (63) and others. Infection appears to occur between the time of the germination of the seed and the appearance of the young seedlings above ground. The germ tubes which develop either from the promycelium or the sporidia penetrate the young shoot of the host and give rise to the mycelium in the growing plant. Reed (97) abstracted the data presented in this bulletin. He discussed briefly the relative resistance of the various groups of sorghums to the covered and loose-kernel smuts, reviewed the literature dealing with these smuts, and gave descriptions of *Sphacelotheca sorghi* and *Sphacelotheca cruenta* as contained herein. He also presented data for 1922, showing the resistance of sorghums to these smuts at the Brooklyn Botanic Garden during that year.

#### LOOSE KERNEL SMUT

The loose kernel smut (*Sphacelotheca cruenta* (Kühn) Potter) was first described in 1872 by Kühn (59) and named by him *Ustilago cruenta* Kühn. Winter (120) recorded it in Germany, Schroeter (104)

in Silesia, Bubák (18) in Bohemia, and Busse (20) in Tanganyika Territory (formerly German East Africa). Kulkarni (63) records it in the Sholapur district of the Bombay Presidency, and Butler (21) notes it in the Central Provinces of India. According to Potter (91) it has been introduced into the United States on seeds of kaoliangs from various parts of China, and this would indicate its more or less widespread distribution in that country. Its presence in Australia or South Africa has not been noted. According to Potter (91), who cleared up the confusion between this species and *S. sorghi* due to Kühn's vague description and definitely established its occurrence in the United States, it was collected by Trelease (111) in Madison, Wis., on plants grown from imported Chinese seed but was incorrectly reported as *S. sorghi*. According to Trelease, it was also collected in the same year by Farlow in the District of Columbia and by Sturtevant in New York.

No definite records are available concerning the extent to which *Sphacelotheca cruenta* causes damage. Kulkarni (63) does not regard it as particularly significant in India, especially as compared with the covered kernel smut. In the United States it seems to occur only sporadically and does not cause any appreciable damage.

Infected plants are usually more or less stunted, and the heads emerge earlier than those of normal plants. Usually all the spikelets are smutted, although a few may escape and be transformed into leafy structures. The glumes are usually enlarged and changed to a deep-green or purple color. The sori may be produced also on the pedicels or other parts of the panicle and occasionally occur on the stalk as well as in the flowers. The presence of these extra-floral sori was early emphasized as one of the distinguishing characteristics of the species (Pl. IV).

The ovaries are transformed into smut balls or false kernels, which are 3 to 18 millimeters long and 2 to 4 millimeters in diameter. The outer membrane is much thinner and more fragile than in the case of the covered smut and is composed largely of more or less spherical cells about 12  $\mu$  in diameter. The membrane incloses the spores, and in the center of the smut ball is the columella, which frequently is curved and is longer than that of *Sphacelotheca sorghi* (Pls. V, VI, and VII).

It is difficult to distinguish between the spores of the two kernel smuts. Those of the loose smut apparently are slightly larger, 5 to 10  $\mu$ , somewhat irregular in shape, and show a slight indication of pitting of the wall.

The germination of the spores has been studied by Brefeld (10), Busse (20), Kulkarni (63), and Butler (21). Germination takes place readily in water and nutrient solutions. A three-celled or four-celled promycelium is produced which buds off sporidia sparingly in water but abundantly in nutrient solutions.

Brefeld (11) demonstrated that infection occurs in the seedling stage, the spores present on the seed constituting the main if not the only source of infection. The subsequent life history is the same as in the case of covered kernel smut.

Potter (91) has recorded some results of inoculation experiments with loose kernel smut. He inoculated six different varieties of sorghum and obtained the following results: Milo, no infection;

Amber sorgho, 10.9 per cent; kafir, 13.8 per cent; broomcorn, 6.9 per cent; kaoliang, 10.3 per cent; and Freed sorghum, 5 per cent infection. Reed (97) also has made further studies of the resistance of varieties.

#### HEAD SMUT

Kühn<sup>3</sup> in 1875 first described the head smut of sorghum, *Sorosporium reilianum* (Kühn) McAlpine, from a specimen which Reil sent to him from Egypt in 1868, naming it *Ustilago reiliana* Kühn. In the studies made by Clinton (22) in 1897 the smut was transferred to the genus *Cintractia* as *Cintractia reiliana* (Kühn) Clinton. Later Clinton (24) transferred it to the genus *Sphacelotheca* as *Sphacelotheca reiliana* (Kühn) Clinton. Norton (80) in 1898 noted the fact that the spores showed a tendency to cling together in spore balls, thus resembling a *Sorosporium*. McAlpine (70) emphasized this characteristic and transferred the fungus to the genus *Sorosporium* as *Sorosporium reilianum* (Kühn) McAlpine.

Head smut is particularly interesting, because it occurs on two distinct genera, *Holcus* and *Zea*, and is rather widely distributed on both hosts. On sorghum, Barber (8) has given its distribution in Madras Presidency, and Kulkarni (63) states that it occurs sporadically in the Bombay Presidency. Butler (21) records it in the Punjab, United Provinces, and Central Provinces, as well as the Bombay and Madras Presidencies; it is not known in eastern India. Hori (49) records its occurrence in Japan. Busse (20) reports it in Tanganyika Territory; Hennings (46) lists it in northern Africa, East Africa, and Madagascar; Snowden (105) in Uganda; and Briton-Jones (14) in Egypt. Hauman-Merck (44) states that it is very rare in Argentina. It has frequently been collected in Europe. Winter (120) records it in Germany, Prillieux (93) in France (mentioned under the name *Ustilago destruens*), Bubák (18) in Bohemia, Turconi (113) in Italy, Munerati (78) in Italy on *Holcus halepensis*, Frago (39) in Spain, Malkoff (72) in Bulgaria on *H. halepensis*, and Ranojevic (94) in Serbia on *H. halepensis*.

The first record of its occurrence on sorghum in the United States was made by Failyer and Willard (38) on Red Liberian sorgho in Kansas.<sup>4</sup> Kellerman and Swingle (58) mention the collection of the smut on Amber sorgho in New Jersey by Prof. B. D. Halsted in the same year. Tracy and Earle (110) reported it from Mississippi. Prof. S. M. Tracy collected specimens on sorghum in November, 1888, at Starkville, Miss., labeling them *Cintractia sorghi*. Of three specimens at the New York Botanical Garden two are typical of *Sorosporium reilianum*. The third shows the head only partially infected, some branches of the panicle appearing more or less distinct. The spores, however, are typical of the species. Dr. B. M. Duggar<sup>5</sup> collected a specimen in Alabama in 1892. According to Clinton (26) it has been collected in Illinois, Iowa, Kansas, Minnesota, Mississippi, Nebraska, New Jersey, Ohio, and Texas. Apparently it is not very abundant but occurs sporadically, especially in the Great Plains area, where it is frequently found on Red Amber sorgho. Recently Mackie

<sup>3</sup> *Ustilago reiliana* Kühn. In Rabenhorst, Fungi Europaei Exsiccati, ed. nova, s. 2, cent. 20, no. 1998. 1875.

<sup>4</sup> Specimens of the original collection are in the mycological herbarium of the Kansas State Agricultural College.

<sup>5</sup> This specimen is in the mycological herbarium of the Brooklyn Botanic Garden.

(71) found it in a volunteer crop of Orange sorgho at Davis, Calif., 15 per cent of the plants being infected. During the last few years head smut has become somewhat prevalent in Red Amber sorgho at the Hays (Kans.) Branch Experiment Station, and this has reduced the value and popularity of this variety. Freed sorghum also has been infected with head smut to a considerable extent.

The first report of the occurrence of head smut on maize was made in 1876 by Cooke (27), who collected it in India and listed it under the name of *Ustilago pulveracea* Cooke. Passerini<sup>6</sup> in the same year described the form on maize in Italy as *Ustilago reiliana* f. *zeae*. Cugini (28) and Mottareale (75) also have described its occurrence in Italy, Bubák (18) records it in Bohemia, Garbowski (42) in Russia, and Butler (21) in India, where it occurs chiefly in Kashmir, being probably more destructive than *Ustilago zeae*. It also occurs sporadically in the Punjab and northern Bombay. Both Mundy (76, 77) and Evans (35) report this smut as common in South Africa, and McAlpine (69, 70) and Johnston (50, 51) record it as common and destructive in Australia.

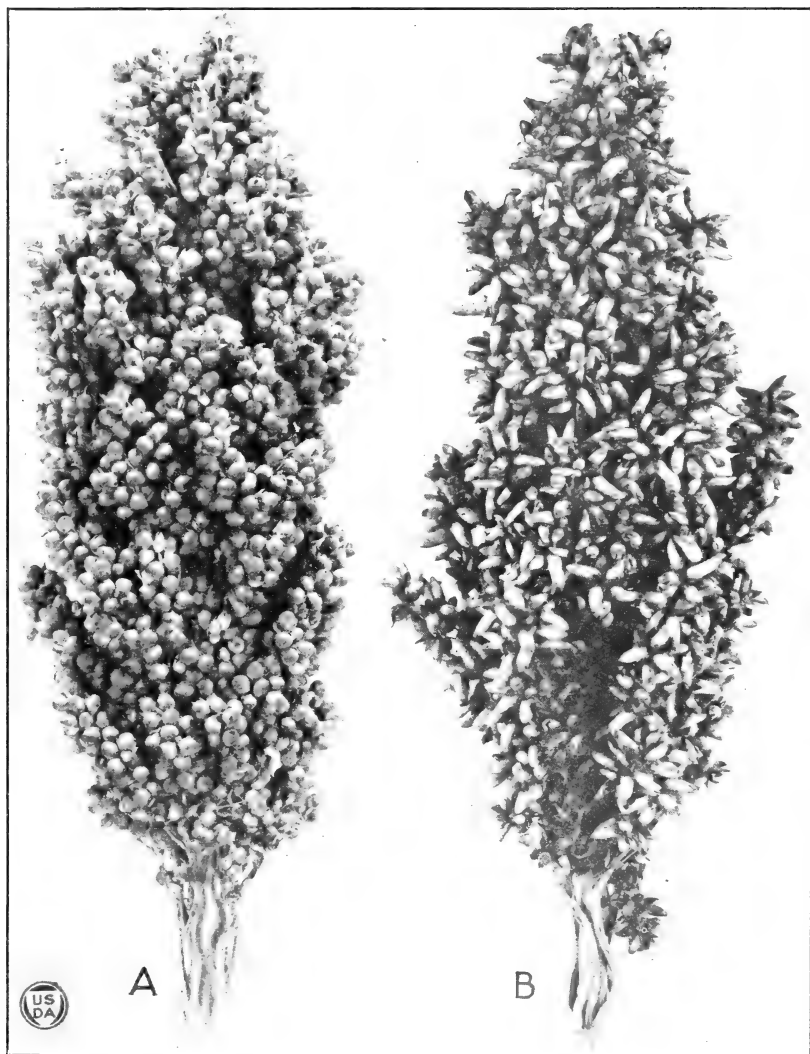
The first record of its occurrence on maize in the United States was made by Norton (79) in 1895.<sup>7</sup> Norton, and later Hitchcock and Norton (48), described the head smut on maize as not uncommon in certain fields in Kansas during the season of 1895. Clinton (26) in 1906 reported it only from Kansas and Ohio. Mackie (71) in 1919 found this smut in a field of King Philip hybrid maize near Stockton, Calif. Practically all the plants in a restricted area of the field were smutted. Dana and Zundel (30, 31) in 1919 found this smut on maize in two fields in the vicinity of Pullman, Wash. In one field they found 40 per cent of the plants smutted. Parker (81) has noted its wide distribution in that State.

The head smut on sorghum produces a very characteristic appearance. The entire inflorescence usually is involved and is converted into a spore mass protected by a transient whitish membrane. No outstanding difference between smutted and normal plants can be noted until the heads begin to form. Then a difference in the size of the heads is observed, the infected panicles remaining much smaller than the normal. As the panicles emerge from the boot the difference is very striking. The spores are interspersed with the stringlike remnants of the fibrovascular bundles of the host tissue. When the membrane breaks, the spores are rapidly disseminated, the vascular strands remaining intact. Occasionally the fungus does not form spores in the affected panicles but causes an elongation and proliferation of the spikelets (Pl. VIII).

In maize the smut is first observed in the tassel, which sometimes is converted into a mass of smut; in other cases the individual flowers are much enlarged or deformed. Sometimes sori are not produced and consequently the flowers may grow out into leafy structures. The ear, if affected, commonly is converted into a mass of smut inclosed by the bracts. The rudimentary ears found on an infected plant often are transformed into distorted leafy structures. When the tassel is

<sup>6</sup> Passerini, G. *Ustilago reiliana* Kühn. In Rabenhorst, *Fungi Europaei Exsiccati*, ed. nova, s. 2, cent. 21, no. 2096. 1876.

<sup>7</sup> The original specimens collected by G. L. Clothier and J. B. S. Norton, July, 1895, Manhattan, Kans., are in the mycological herbarium of the Kansas State Agricultural College.



*SPHACELOTHECA SORGHII* (LINK) CLINTON ON SUMAC SORGO

*A*, Sound head; *B*, infected head, in which the kernels are replaced by masses of smut spores



FIG. 1.—INFECTED AND SOUND BRANCHES, MINNESOTA AMBER SORGO

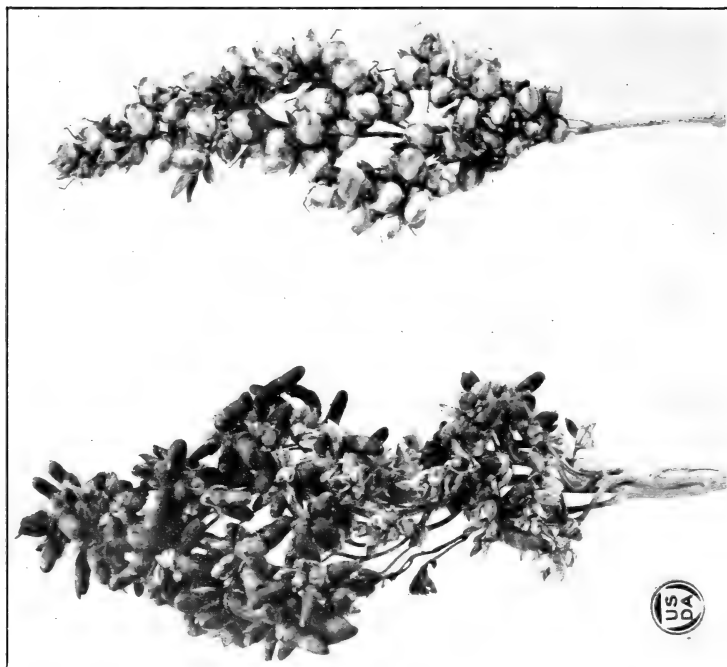


FIG. 2.—INFECTED AND SOUND BRANCHES, BARCHET KAOLIANG

SPHACELOTHECA SORGHII (LINK) CLINTON ON PANICLE BRANCHES OF SORGO AND KAOLIANG



FIG. 1.—INFECTED AND SOUND BRANCHES, DAWN KAFIR  
SPHACELOTHECA SORGHII (LINK) CLINTON ON PANICLE BRANCHES OF KAFIR AND DURRA

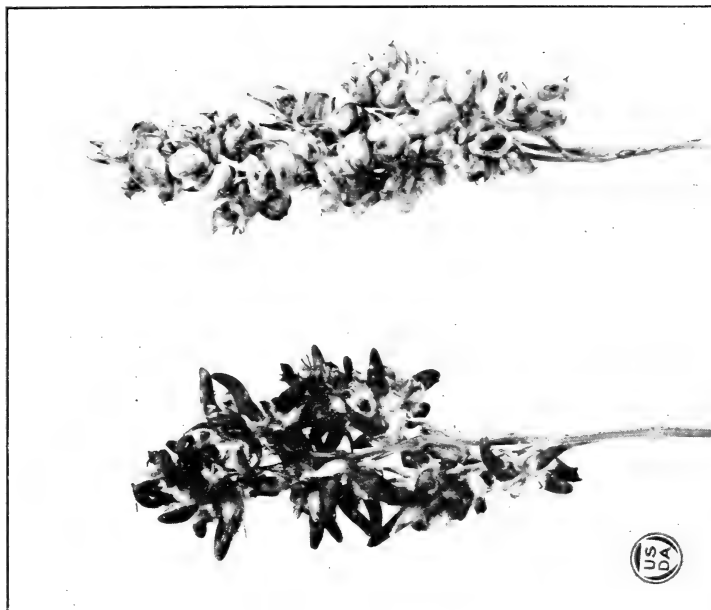


FIG. 2.—INFECTED AND SOUND BRANCHES, BROWN DURRA  
SPHACELOTHECA SORGHII (LINK) CLINTON ON PANICLE BRANCHES OF KAFIR AND DURRA

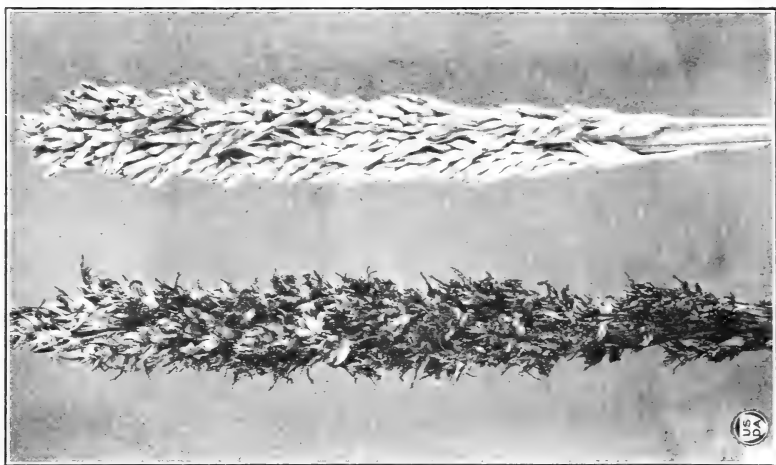


FIG. 2.—LATE AND EARLY STAGES ON RED  
KA FIR

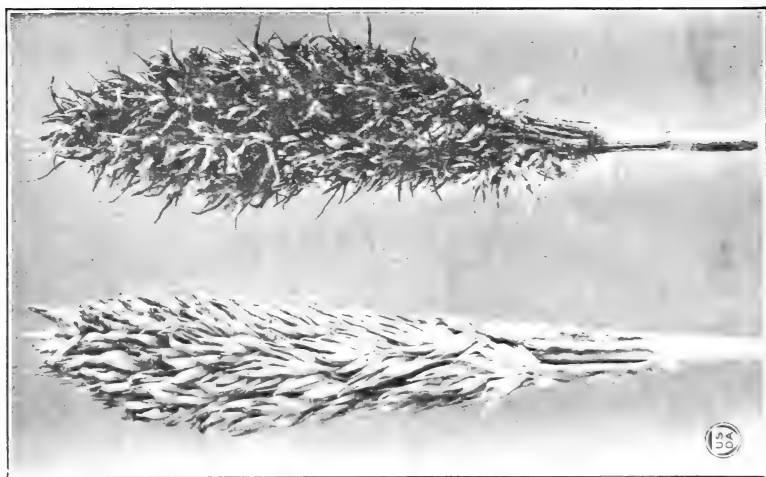


FIG. 1.—EARLY AND LATE STAGES ON  
BROWN DURRA

SPHACELOTHECA CRUENTA (KÜHN) POTTER ON DURRA AND KAFIR



FIG. 1.—EARLY AND LATE STAGES ON DARSO

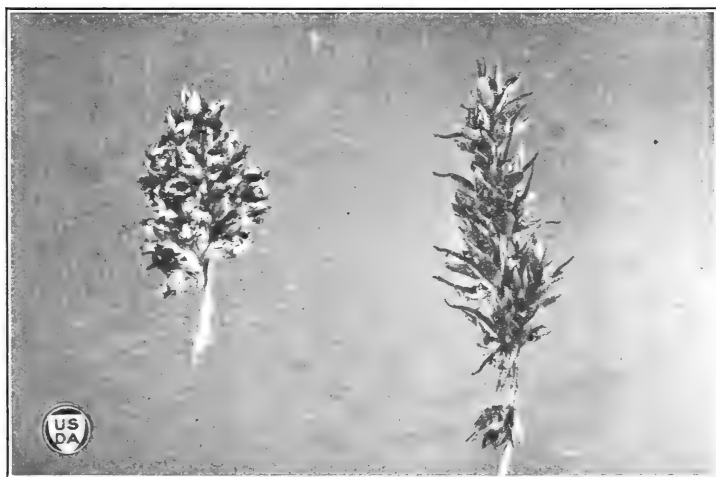


FIG. 2.—EARLY AND LATE STAGES ON RED KAFIR  
SPHACELOTHECA CRUENTA (KÜHN) POTTER ON DARSO  
AND KAFIR

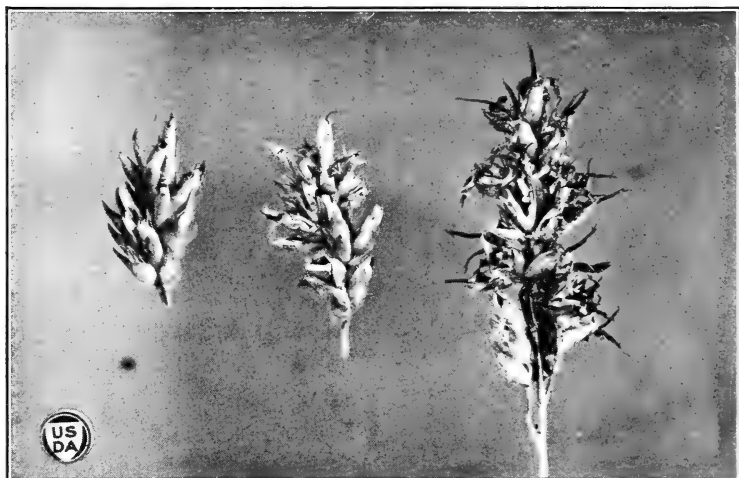


FIG. 1.—EARLY AND LATE STAGES ON SUMAC SARGO

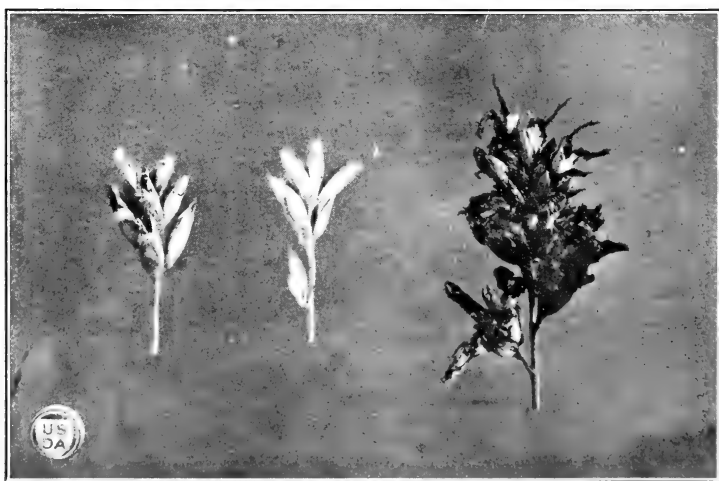


FIG. 2.—EARLY AND LATE STAGES ON SHALLU  
SPHACELOTHECA CRUENTA (KÜHN) POTTER ON SORGO  
AND SHALLU

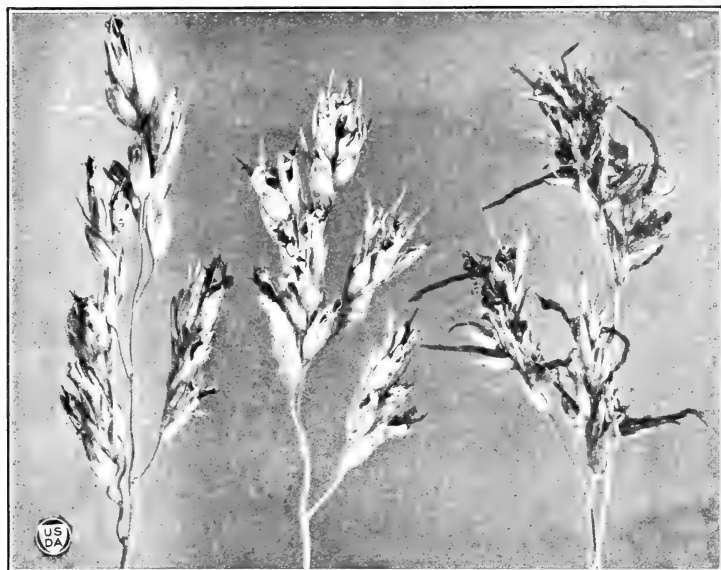


FIG. 1.—EARLY AND LATE STAGES ON BLACK AMBER SORGO

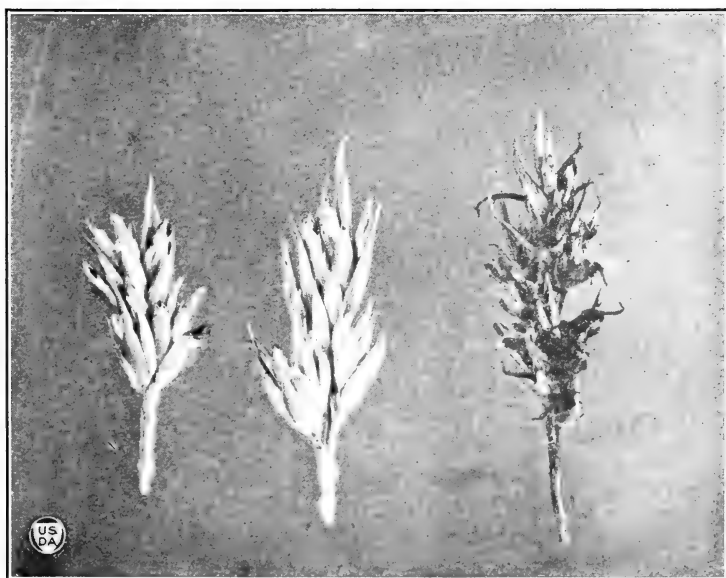
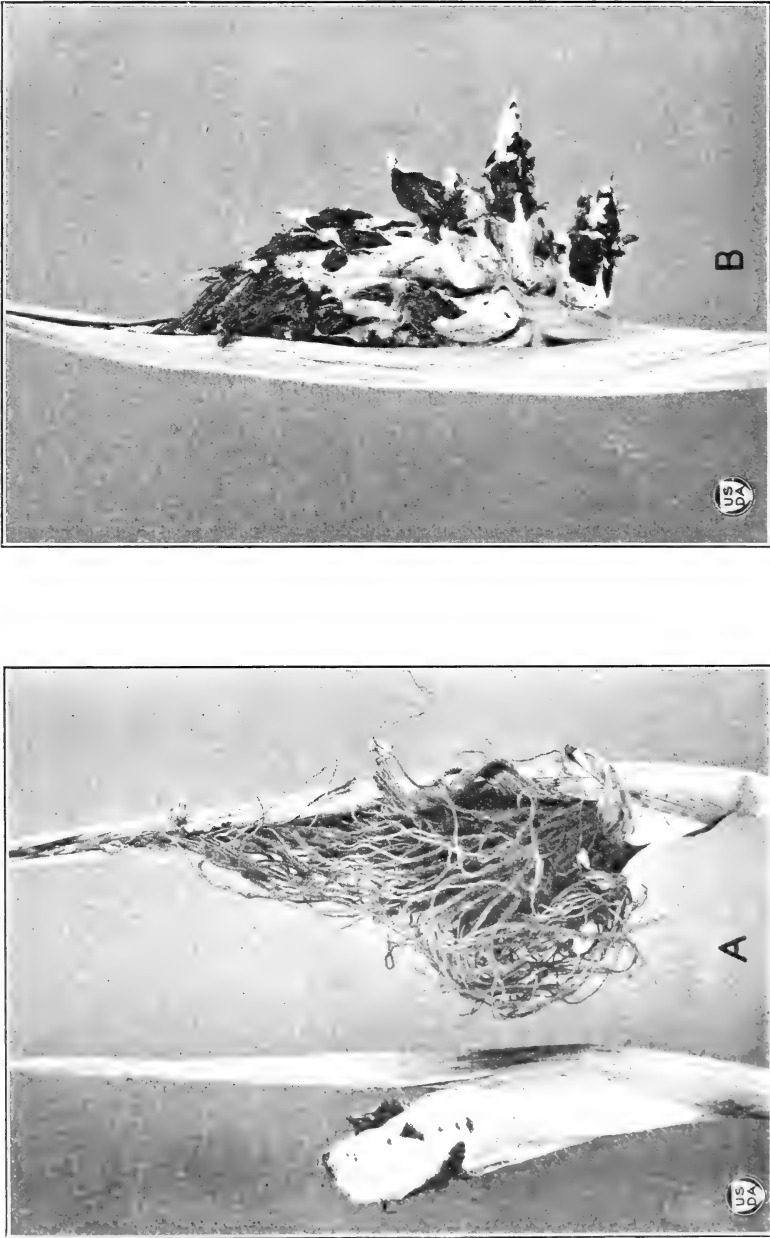
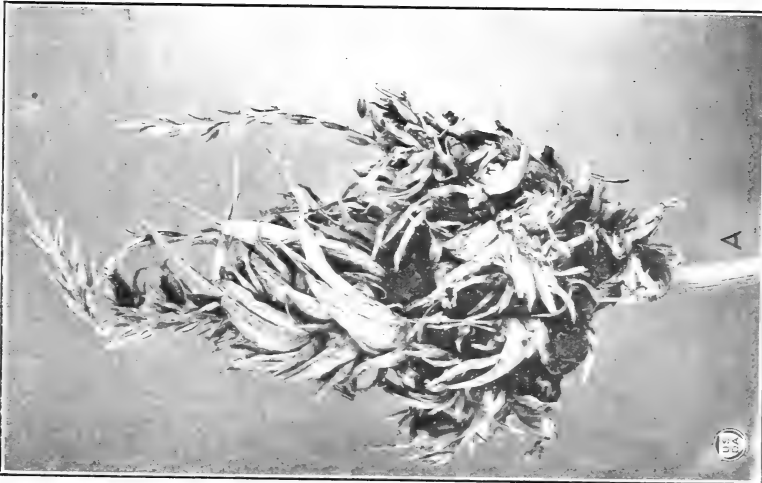
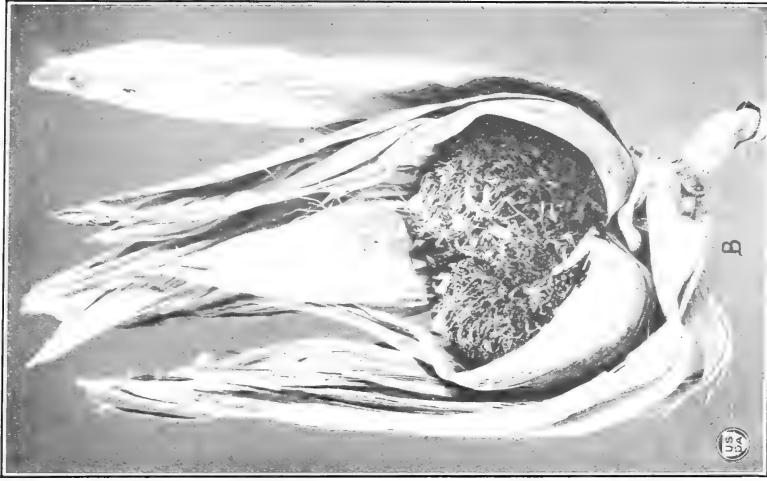


FIG. 2.—EARLY AND LATE STAGES ON BROWN DURRA  
SPHACELOTHECA CRUENTA (KÜHN) POTTER ON SORGO  
AND DURRA



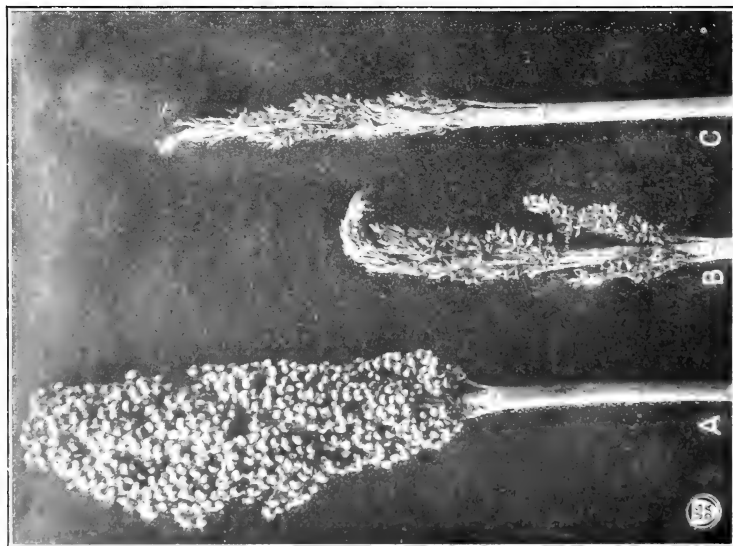
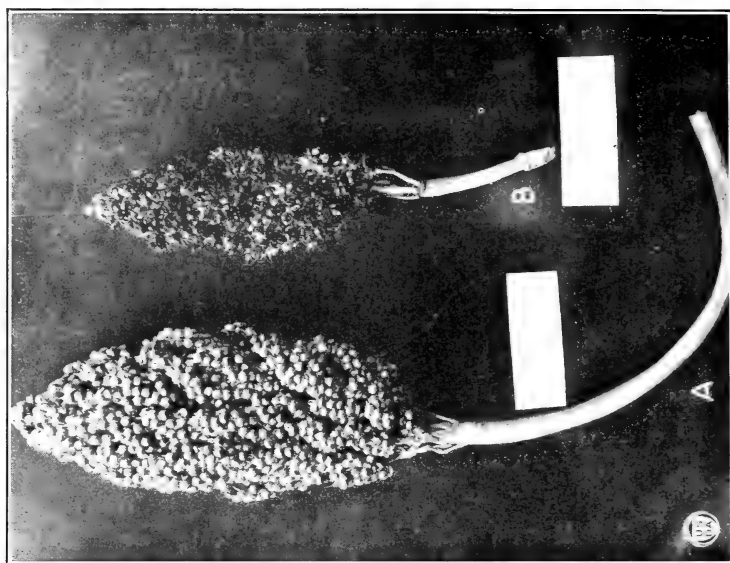
**SOROSPORIUM REILIANUM (KÜHN) MCALPINE ON RED AMBER SORGO**

*A*, Early stage, membrane mostly intact (at left); late stage, membrane broken, spores mostly shed, and remnants of fibrovascular bundles exposed (at right). *B*, Head showing branches of panicle converted into more or less distinct sort



SOROSPORIUM REILIANUM (KÜHN) MCALPINE ON MAIZE

A, Infected tassel; B, infected ear



## SPHACELOTHECA SORGHII (LINK) CLINTON

Fig. 1.—Main (B) and lateral (C) head of *fetorita* infected with kernal smut produced in 1916 by removing the sheath and inoculating the plumule with spores and sporidia. The sound head (A) was grown in 1917 from normal seed from the smutted head of 1916. Fig. 2.—Smutted head of White millo (B) collected at Amarillo, Tex., in 1916. The sound head (A) was grown at Manhattan in 1917 from normal seed on this smutted head

affected the ears also generally are smutted and destroyed, but occasionally one will escape or be only partially attacked. On the other hand, the tassel may escape when the ear is destroyed. The smutted plants frequently are stunted and remain green somewhat longer than normal plants. The smut masses are inclosed in a delicate pinkish white membrane which ruptures at maturity, exposing the spores. In large sori the fibrovascular tissues of the host (Pl. IX) persist, surrounded by the spores.

The spores are united into spore balls, firm at first but later readily breaking up. These are dark brown in color, globose to oval or irregular in form, and 80 to 112  $\mu$  in length. The spores are globose to subglobose or somewhat angular, minutely but densely verruculose, and from 10 to 13  $\mu$  in diameter.

The germination of the spores has been studied by Brefeld (10), Norton (80), McAlpine (70), Potter (90), Kulkarni (63), and Butler (21). Some of these investigators seem to have had no special difficulty in obtaining germination in water or nutrient solutions. On the other hand, Kulkarni and the writers of this bulletin had great difficulty in getting successful results. Potter (90) was seldom able to obtain more than 15 per cent germination in water.

On germination a promycelium is produced, usually four celled, sometimes branched, with sporidia occurring terminally and laterally. In a nutrient solution the sporidia bud abundantly, forming a large number of secondary sporidia.

Several investigators have attempted to produce artificial infection by contaminating the seed or soil at seeding time. Brefeld (10) reports that Kühn succeeded in producing infection with this smut and also *Ustilago cruenta* in the same plant. Passerini (83) states that he was able to infect maize but not sorghum, using spores collected on maize. Kellerman (54) attempted a number of inoculation experiments with head smut. He obtained two infected plants in his greenhouse inoculations. He also inoculated a number of varieties of maize in the field but obtained only two infected plants of pop corn. In another experiment (55) he succeeded in infecting three plants of sweet corn, having inoculated varieties of field corn, sweet corn, pop corn, and sorghum. Kellerman and Jennings (56) report practically complete failure in their inoculation experiments with varieties of dent corn, pop corn, sweet corn, and sorghum, obtaining only one smutted pop-corn plant. Clinton (23) failed to obtain infection by inoculating seed and seedlings. Hori (49) also reports negative results from his inoculation experiments. McAlpine (70) produced infection in a single maize plant by seed inoculation.

Potter (90) recently made an extensive study of this smut. He conducted field experiments at four different stations, Amarillo and Chillicothe, Tex., St. Paul, Minn., and Rosslyn (Arlington Experiment Farm), Va. By using inoculated seed during three years he was able to obtain infection only at Amarillo and Chillicothe; and he came to the conclusion that seed-borne spores are negligible in causing infection, which, instead, takes place from spores present in the soil. The fact that the spores do not germinate readily in water or culture solutions used lends further support to this view. It would seem that the spores may retain their viability in the soil

for considerable periods of time, only a few germinating periodically. The evidence of Potter points also to the fact that infection takes place through the young sprout. Rarely do slightly older plants become infected.

#### SORGHUM SMUTS NOT KNOWN TO OCCUR IN THE UNITED STATES

*Tolyposporium filiferum* Busse.—This smut was described first from East Africa in 1904 by Busse (20), who found it on sorghum at various points in Tanganyika Territory, where apparently it caused no great damage. It is probable that Barber (8) referred to this smut as one of the three which occurred in the Madras Presidency. In his description, the pathological symptoms coincide with those produced by this fungus, although he attributed the cause to *Ustilago reiliana*. Kulkarni (63) reports the occurrence of this smut, described as "long smut," in the Bombay Presidency, stating that it is mostly confined to Sind but also occurs sparingly in the Kathiawar States. In restricted areas it may cause considerable loss, but in the Bombay Presidency as a whole the damage is comparatively insignificant. Butler (21) mentions its occurrence in the Madras Presidency and Sind. Thomas (109) refers to its occurrence in Mesopotamia. According to Briton-Jones (14) it is common in Egypt. This smut has not been reported in the United States.

In long smut only a few flowers of a head are infected. The glumes of the spikelet remain unaltered, but the ovaries are transformed into smut balls or false kernels. These false kernels are cylindrical, usually curved and abruptly pointed at the distal end. They vary from 6 to 25 millimeters in length and 4 to 6 millimeters in diameter. At maturity the shining grayish white membrane of the smut ball opens at the tip, occasionally cracking in the middle. The interior of the smut ball consists of a mass of smut spores surrounding a bundle of 8 to 10 or more dark-brown strands of host tissue, usually joined at the base. These are the remnants of the fibrovascular bundles.

The spores are grouped in firm spore balls, which are irregular in shape and 40 to 120  $\mu$  in size. The individual spores are brown, spherical or oblong, with echinulate walls on the free side. They vary in size from 8 to 14  $\mu$  in diameter. They germinate readily in water and in various nutrient solutions. The promycelium is sometimes branched, generally three celled, and bears sporidia apically and laterally at the septa, frequently in clusters. The sporidia in turn produce secondary spores by budding or grow out into long tubes. Branching chains of aerial sporidia are formed at the surface of a culture.

It is not known how infection occurs. Seed treatments appear to be of no value in preventing the disease, and this would seem to indicate that seed-borne spores are not the source of infection. It remains to be determined whether individual flowers are infected by the air-borne secondary sporidia or whether seedling infection takes place from spores present in the soil.

*Tolyposporium volkensii* P. Henn.—This sorghum smut was described by Hennings (32, p. 48-49) from specimens sent by Volkens, who collected them in Kilimanjaro, East Africa. The smut was

reported as somewhat injurious to the sorghums in the station garden of Marangu. This smut occurs in the individual flowers of the head, but many flowers remain normal and produce seed. The infected ovaries are converted into a more or less spherical smut ball, 5 to 8 millimeters in diameter. The spherical or ovoid spores are united into spore balls, consisting of 5 to 10 spores. This species differs from *Tolyposporium filiferum* in the size and shape of the smut ball, the spore balls also being smaller and consisting of fewer spores. It has not been noted elsewhere so far as the writers are aware.

*Ustilago bulgarica* Bubák.—Bubák (15) described this species from a single collection on sorghum grown in the experiment field at Sadovo, Bulgaria. It infects the ovaries of the flowers, forming smut balls which extend considerably beyond the glumes and are covered with a gray membrane which is furrowed and pitted. The general appearance of the head is unchanged. The spore mass is greenish brown. The spores are bright olive green, spherical or ovoid, 5.5 to 9  $\mu$  in diameter, with a thin, smooth wall. This species is closely related to *Sphacelotheca cruenta* (Kühn) Potter. Infected panicles, however, remain normal in general appearance, the sori being confined to the ovaries.

*Ustilago sorghicola* Spég.—Spegazzini (107) described this sorghum smut from specimens gathered near La Plata, Argentina. The ovaries are converted into subcylindrical smut balls. The spores are smooth, 7 to 8  $\mu$  in diameter. It is very similar to *Sphacelotheca sorghi* (Link) Clinton, if not identical with it.

*Sorosporium simii* Evans.—Evans (37) has described this new species on Johnson grass (*Holcus halepensis*) from Natal, South Africa. The sori destroy the entire inflorescence while still inclosed in the sheathing blade; they are 5 to 7 centimeters long and 1 to 2 centimeters broad, at first covered with a rather thick white membrane. The spore balls are subglobose or ellipsoid, black, 60 to 150  $\mu$  in diameter. The spores are globose or subglobose, olivaceous or olivaceous brownish, very delicately echinulate, 12 to 13  $\mu$  in diameter. It is impossible from the description to distinguish this smut from *Sorosporium reilianum* (Kühn) McAlpine. The fact that *S. reilianum* has been reported frequently on *Holcus halepensis* by other workers lends further evidence as to the identity of *S. simii* with the head smut.

*Sorosporium ehrenbergii* Kühn.—Schweinfurth collected a smut on sorghum near Cairo, Egypt, which was distributed by De Thümen in *Mycotheca universalis*, No. 725, as *Ustilago reiliana* Kühn f. *sorghicervini*. Kühn (61, 62) studied the fungus and decided that it belonged to the genus *Sorosporium* because the spores were united in spore balls. According to his description of the new species, the smut balls are 8 to 13 millimeters long and 3 to 5 millimeters wide. The spore balls are spherical to ovoid in shape and measure 36 to 94  $\mu$  by 43 to 131  $\mu$ . The spores are spherical or irregular in shape, verrucose, and measure 12.4 to 17.2  $\mu$  in diameter. The specimen of De Thümen's *Mycotheca universalis*, No. 725, at the New York Botanical Garden was examined and in external appearance can not be distinguished from *Sphacelotheca sorghi* (Link) Clinton. The spores were found also to be indistinguishable. Kühn's description, however, corresponds closely to that of *Sorosporium reilianum*.

*Endothlaspiis sorghi* Sorok.—Sorokine (106) has described this species from a collection made on sorghum in central Asia. According to his description the membrane or pseudoperidium is composed of large spherical cells. The spores are spherical or irregular, verrucose, and measure 7 to 10  $\mu$  in diameter. The species is very closely related to *Sphacelotheca sorghi* (Link) Clinton, if not identical with it.

### CLASSIFICATION OF THE SORGHUMS

As already noted, the sorghums constitute a highly diversified group of plants. However, from the agronomic standpoint they may be arranged in five divisions:

- (1) Perennial sorghum, including Johnson grass.
- (2) Grass sorghum, including Sudan grass, Tunis grass, tabucki grass, toura grass, and Kamerun grass.
- (3) Broomcorn, largely grown for the brush used in making brooms, though the stems and leaves have some value as fodder.
- (4) Sorgo, or saccharine sorghum, grown mainly for forage and to a less extent for sirup.
- (5) Grain sorghum, grown mostly for grain; some of them, especially the kafirs, are also valuable as forage plants. This group includes the kafirs, durras, milos, feterita, kaoliangs, and shallu.

Ball (3) has made extensive studies of the varieties of sorghums which have been introduced into this country and has suggested a system of classification in which he recognizes seven groups. Two of these correspond to the agronomic classification, namely, broomcorn and sorgo. The remaining five groups are agronomically classified as grain sorghums; these are durra, milo, kafir, shallu, and kaoliang. In addition to these, another group must be added to include the grass sorghums (86), such as Sudan grass.

In presenting the results obtained in the inoculation experiments with kernel smut, the data on each of the seven groups of the sorghums proposed by Ball are reported separately. The data on Sudan grass are included with those of the sorgos. The results with various miscellaneous forms, mostly hybrids between members of the other groups, are reported under the heading "Miscellaneous sorghums."

### LOCATION OF THE EXPERIMENTS

The senior writer began his experiments with the covered kernel smut of sorghum at Columbia, Mo., in 1915, while botanist at the Missouri Agricultural Experiment Station. The investigations were continued there in 1916, 1917, and 1918. From October 1, 1918, to December 31, 1920, he was pathologist in charge of cereal-smut investigations in the Office of Cereal Investigations, Bureau of Plant Industry.

The junior writer, in cooperation with A. A. Potter, formerly of the Office of Cereal Investigations, Bureau of Plant Industry, conducted experiments at the Kansas Agricultural Experiment Station, Manhattan, Kans., and the Cereal Field Station, Amarillo, Tex., from 1916 to 1918.

The investigations were continued jointly by both writers at Amarillo in 1919, at Manhattan from 1919 to 1921, at the Arlington

Experiment Farm, Rosslyn, Va., in 1919 and 1920, and at the Brooklyn Botanic Garden, Brooklyn, N. Y., in 1921.

### METHODS EMPLOYED IN THE VARIETAL STUDIES

In the first experiments at Columbia, Mo., in 1915 (95), seed of 22 varieties of sorghums, including sorgos, broomcorns, kaoliangs, kafirs, durras, and milos, were inoculated with spores collected the previous autumn from kafir grown in the vicinity of Columbia. Four varieties, feterita, Dwarf Yellow milo, Standard Yellow milo, and a durra, remained free from infection. The other varieties had a percentage of infection ranging from less than 1 to more than 31 per cent. The studies at Columbia (96, 98) were continued in 1916, 1917, and 1918, an additional number of varieties being used each season.

The seed of the varieties of sorghum grown at Columbia was obtained from a number of sources, for the most part from seedsmen, but also from the agricultural experiment stations of Missouri, Louisiana, Kansas, Oklahoma, and Texas. The original seed of many of these varieties was also used at the Arlington Experiment Farm, Rosslyn, Va., in 1919 and 1920 and at the Brooklyn Botanic Garden in 1921. In addition, a large number of varieties was obtained from B. E. Rothgeb, of the Office of Cereal Investigations, and H. N. Vinall, of the Office of Forage-Crop Investigations, Bureau of Plant Industry, and used in the seedings at Rosslyn and Brooklyn. Many of the original samples of seed were used in two or more seasons, no attempt being made to collect seed from one crop for use during the next year.

The seed received from the various seedsmen was listed under various names. These varieties were all carefully examined and compared with authentic material. Dr. C. R. Ball and B. E. Rothgeb, of the Office of Cereal Investigations, and H. N. Vinall, of the Office of Forage-Crop Investigations, have rendered valuable assistance in the identification of the collections.

In several cases the seed samples contained mixtures of varieties. This was especially true of the sorgos. So far as possible, however, the rows were carefully rogued before the counts were made. Failure to rogue completely may account for the occasional appearance of smut in certain varieties which otherwise have been free from smut.

As previously stated, the spores first used for inoculation were collected in the fall of 1914 from kafir growing in the vicinity of Columbia, Mo. In subsequent years smutted heads were taken from some of the varieties in the experimental plat, and these furnished a supply of spores for inoculation. Spore germinations were always made to determine their viability.

From 100 to 200 seeds of the different varieties were placed in packets, inoculated by dusting heavily with the spores, and then sown as soon as possible. Usually an uninoculated series of the varieties was sown also as a check. Very little smut appeared in the uninoculated rows, indicating that the original seed used was almost entirely free from smut contamination.

The rows usually were 40 inches apart. The length of row varied, but an attempt was made to have at least 100 plants at maturity.

In many cases the number of plants was very much less than this, poor germination having resulted in thin stands. The plants, when necessary, were thinned so as to be approximately 4 to 6 inches apart.

The investigations at Manhattan, Kans., and Amarillo, Tex., were begun in 1916. Potter and Melchers (92) reported briefly on the results of their experiments during 1916 and 1917 at these two stations. They state that milo and feterita, a few durras, and a dwarf kaoliang<sup>8</sup> proved highly resistant. Other varieties of durra, the kafirs, broom-corns, and sorghos were found to be generally susceptible. The varieties of kaoliang showed a moderate degree of resistance. Melchers (74) made a further brief report on this work.

The seed used at Manhattan and Amarillo was obtained from the Office of Cereal Investigations and from Prof. John H. Parker, of the department of agronomy of the Kansas Agricultural Experiment Station, and consisted of lots bearing Cereal Investigations, Seed and Plant Introduction, and Kansas agronomy department numbers. In so far as possible, several heads of each variety were bagged each season, and the seed from these was used the following year.

The smut for inoculation was collected in the autumn and kept in a dry, cool place. Later it was ground and sifted through a fine screen so as to exclude all grain. Germination tests of the spores were made in order to be certain of their viability. The seed to be inoculated was placed in a small box and sufficient smut was added to give the seed a noticeable brown color after shaking. The seed then was sown 1½ inches deep in rows 30 inches apart. The plants were thinned to one every 8 to 10 inches in the row.

#### INOCULATION EXPERIMENTS WITH COVERED KERNEL SMUT

The percentages of infection obtained in the inoculation experiments with covered kernel smut (*Sphacelotheca sorghi* (Link) Clinton) are shown in Tables 1 to 7. These tables also include the varietal name and seed number of each strain and the station and year each was grown. If a strain was grown two or more years the average percentage of infection, based on the total number of plants grown and total number infected, also is shown.

#### RESULTS WITH SHALLU

Shallu (102) belongs to a group of sorghums commonly grown in some parts of India and central East Africa. The so-called rabi jowar, or winter sorghum, of India, which is sown in September and October and harvested in February and March, consists very largely of different strains of shallu. The crop is grown during the period of least rainfall, and smut seems to be less prevalent in it than in the kharif varieties which are grown during the summer season and spoken of as the monsoon crop. The kharif varieties are very largely durras.

Shallu was imported from India about 1890 by officials of the Louisiana Agricultural Experiment Station. It was grown for several years under the name "Egyptian wheat" and then discarded only to

<sup>8</sup> This so-called dwarf kaoliang, C. I. No. 293 and S. P. I. 22010, is different from the rest of the kaoliang group, according to C. R. Ball, and probably represents either a selection or a hybrid from one of the near durras from India.

be introduced later into various other parts of the country. As early as 1905 it was grown in Texas under the name "California wheat." Other common names are California rice corn, California golden sorghum, Egyptian rice, Egyptian wheat, Mexican wheat, and Mexican Desert wheat or rice corn. These names are all somewhat misleading and have been used for purposes of exploitation. Apparently only one variety of shallu has been grown in the United States. It is of little value as compared with the other sorghums.

Six different lots of shallu were grown at Columbia, Mo. The total number of plants obtained was 1,235, of which 342, or 27.6 per cent, were infected. Shallu (C. I. No. 85) was grown four years at Manhattan and three years at Amarillo; at Manhattan, 23.2 per cent of the plants were infected, and at Amarillo, 19 per cent. At Brooklyn 144 plants of three different lots were grown, 55, or 38.1 per cent, being infected. At Rosslyn 32 out of 90 plants of two lots grown were infected, or a total of 35.5 per cent. The detailed data are shown in Table 1.

TABLE 1.—*Results of inoculation experiments with spores of covered kernel smut on strains of shallu at five stations in one or more of the seven years from 1915 to 1921, inclusive*

Strain and station	Number of plants grown							Percentage of plants infected							
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	Average
Mo. No. 5: Columbia	341							29.0							29.0
Mo. No. 10: Columbia	235							20.0							20.0
Mo. No. 15: Columbia	192							22.9							22.9
Mo. No. 46: Columbia		113	63	84					52.2	71.4	0				40.0
Mo. No. 62: Columbia			94	1						51.1	0				50.5
Mo. No. 76: Columbia				112							0				0
Rossllyn						65							32.3		32.3
Mo. No. 206: Brooklyn							14							28.6	28.6
C. I. No. 85: Manhattan		91	18	53	2				17.6	16.7	35.8	0			23.2
Brooklyn							94							39.4	39.4
Amarillo		61	239		137				9.8	18.0		24.8			19.0
Rossllyn						25							44.0		44.0
Agrost. No. 2650: Brooklyn							36							38.9	38.9

In these experiments shallu was very susceptible to covered kernel smut. Its freedom from smut in India may be due to environmental conditions or to varieties which differ in their susceptibility from the one introduced into the United States.

#### RESULTS WITH SORGOS AND GRASS SORGHUMS

Apparently the first variety of sorgo, or sweet sorghum, to reach the United States came from China by way of France (3). In 1851, seed of a variety of sorgo was sent to France from the island of Tsungming. Only one seed grew, producing a plant very similar to some of our forms of Amber sorgo. Most of our strains of Black

Amber sorgo probably have been produced from this Chinese introduction. Later importations of sorghums were made from China, but no additional saccharine varieties.

TABLE 2.—Results of inoculation experiments with spores of covered kernel smut on varieties of sorgos and grass sorghums at five stations in one or more of the seven years from 1915 to 1921, inclusive

Variety, strain, and station	Number of plants grown							Percentage of plants infected							Average
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	
BLACK AMBER GROUP															
Black Amber, Mo. No. 70:															
Columbia			104	99					28.8	0					14.8
Brooklyn							31							6.5	6.5
Black Amber, Mo. No. 127:															
Brooklyn							51						58.8		58.8
Rosslyn						85						44.7			44.7
Black Amber, Mo. No. 209:															
Columbia			90						20.0						20.0
Brooklyn							42						50.0		50.0
Black Amber, F. C. I. No. 7038:															
Brooklyn							113						55.8		55.8
Black Amber, S. P. I. No. 32384:															
Manhattan		117	200	113	124	411	108	27.4	21.0	40.7	13.7	9.0	7.4		17.0
Amarillo		57	112	167	608			12.3	14.3	15.6	5.3				8.6
Collier, Mo. No. 47:															
Columbia		416	94	107				19.7	23.4	1.9					17.2
Brooklyn							37							43.2	43.2
Collier, S. P. I. No. 19770:															
Brooklyn							12						66.7		66.7
Rosslyn						82							42.7		42.7
Collier, Kansas station:															
Manhattan				104	30					32.7	46.7				35.8
Amarillo				54	293					48.1	31.7				34.3
Black Dwarf, Kansas station:															
Manhattan				74	126					23.0	4.8				11.5
Amarillo				172	365					29.1	1.4				10.2
Dakota Amber, Mo. No. 48:															
Columbia		369	226	101				16.5	21.2	0					15.6
Dakota Amber, Mo. No. 141:															
Rosslyn						70							44.3		44.3
Dakota Amber, F. C. I. No. 1528:															
Manhattan		185		36				15.1		41.7					19.5
Amarillo		156	81	42				9.0	12.3	21.4					11.8
Early Amber, Mo. No. 207:															
Brooklyn							79							12.7	12.7
Early Amber, S. P. I. No. 28026:															
Rosslyn						8							37.5		37.5
Folger Early, F. C. I. No. 1480:															
Manhattan					73							61.6			61.6
Amarillo					256							50.8			50.8
Rosslyn						67						23.9			23.9
McLean, S. P. I. No. 34985:															
Brooklyn							85							9.4	9.4
Rosslyn						31							16.1		16.1
Minnesota Amber, Mo. No. 3:															
Columbia	392							10.5							10.5
Brooklyn							26							30.8	30.8
Minnesota Amber, Mo. No. 9:															
Columbia	266							9.8							9.8
Minnesota Amber, Mo. No. 52:															
Columbia		193	103	137				14.5	10.7	2.9					9.9
Brooklyn							21							14.3	14.3
Minnesota Amber, Mo. No. 93:															
Columbia				91						15.4					15.4
Brooklyn							11							9.1	9.1
Rosslyn						105							9.5		9.5
Minnesota Amber, F. C. I. No. 01950:															
Manhattan					105							11.4			11.4
Brooklyn							44							6.8	6.8
Amarillo					279							4.7			4.7
Rosslyn						87							13.8		13.8

TABLE 2.—Results of inoculation experiments with spores of covered kernel smut on varieties of sorghos and grass sorghums at five stations in one or more of the seven years from 1915 to 1921, inclusive—Continued

Variety, strain, and station	Number of plants grown							Percentage of plants infected							Average
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	
RED AMBER GROUP															
Early Rose, Mo. No. 130:															
Manhattan					91							44.0			44.0
Brooklyn							53							60.4	60.4
Amarillo					945							27.2			27.2
Rosslyn						54							18.5		18.5
Early Rose:															
Columbia			97	83					55.7	0					30.0
Red Amber, Mo. No. 78:															
Columbia				157						0					0
Red Amber, S. P. I. No. 17548:															
Manhattan		382	148	125	123	390	114	6.8	15.5	30.4		7.3	13.3	10.5	12.5
Amarillo		348	295	131	670			8.3	5.1	16.8		6.1			7.4
Rosslyn						60							8.3		8.3
Red Amber, F. C. I. No. 1534:															
Manhattan		227	136	115	138			7.9	18.4	27.8		14.5			15.4
Amarillo		169	150	132	581			1.2	6.0	2.3		13.6			9.0
ORANGE GROUP															
Colman, Mo. No. 53:															
Columbia		336	114					64.3	64.9						64.4
Colman, S. P. I. No. 2324:															
Brooklyn							20							75.0	75.0
Rosslyn		139						37.4							37.4
Colman, Kansas station:															
Manhattan				79	74					29.1	27.0				28.1
Amarillo				57	891					42.1	35.8				36.2
Early Orange, Mo. No. 4:															
Columbia	376						27.7								27.7
Early Orange, Mo. No. 77:															
Columbia				88						0					0
Brooklyn							18						44.4		44.4
Rosslyn						40						5.0			5.0
Early Orange, Mo. No. 82:															
Columbia				85						0					0
Brooklyn							34						58.8		58.8
Rosslyn						66						28.8			28.8
Early Orange, Mo. No. 208:															
Brooklyn							55						50.9		50.9
Kansas Orange, Mo. No. 54:															
Columbia		253	113	56				18.6	42.5	0					22.5
Kansas Orange, Kansas station:															
Manhattan						202	69					9.4	10.1		9.6
Kansas Orange, F. C. I. No. 2025:															
Brooklyn							8						12.5		12.5
Orange, Mo. No. 79:															
Columbia				90						0					0
Brooklyn							10						80.0		80.0
Rosslyn						39						30.8			30.8
Orange, Mo. No. 92:															
Columbia				75						2.7					2.7
Brooklyn							18						55.6		55.6
Rosslyn						72						27.8			27.8
Orange, Mo. No. 210:															
Columbia			39	87					53.8	0					16.7
Brooklyn							16						81.3		81.3
Orange, F. C. I. No. 1438:															
Manhattan		25	200	141				48.0	22.5	52.5					35.8
Amarillo		42	224	168				7.1	25.4	24.4					23.3
Orange, C. I. No. 113a:															
Manhattan					78	195						70.5	8.7		26.4
Amarillo					641							49.5			49.5
Rosslyn						51							37.3		37.3
Planter, S. P. I. No. 17539:															
Amarillo					4							100.0			100.0
Silverton, Mo. No. 138:															
Manhattan					111							12.6			12.6
Amarillo					699							9.4			9.4
Rosslyn						87							1.1		1.1

TABLE 2.—*Results of inoculation experiments with spores of covered kernel smut on varieties of sorghos and grass sorghums at five stations in one or more of the seven years from 1915 to 1921, inclusive—Continued*

Variety, strain, and station	Number of plants grown							Percentage of plants infected							Average
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	
SUMAC GROUP															
Dwarf Ashburn, Mo. No. 50:															
Columbia		259	111	55					28.2	37.8	0				27.1
Sumac, Mo. No. 11:															
Columbia	389							10.3							10.3
Sumac, Mo. No. 55:															
Columbia		370	105					39.2	42.9						40.0
Brooklyn							15							80.0	80.0
Sumac, Mo. No. 88:															
Rosslyn						65						36.9			36.9
Sumac, F. C. I. No. 1831:															
Brooklyn							94							63.8	63.8
Rosslyn						99						13.1			13.1
Sumac, S. P. I. No. 35038:															
Manhattan		200	86		56			34.5	8.1		12.5				24.3
Amarillo			197		506				6.6		10.9				9.7
MISCELLANEOUS GROUP															
Denton, Mo. No. 144:															
Rosslyn						14						7.1			7.1
Gooseneck, Mo. No. 91:															
Columbia				30						0					0
Rosslyn						22						0			0
Gooseneck, Agrost. No. 2652:															
Manhattan							28							32.1	32.1
Brooklyn							58						0		0
Honey, Mo. No. 66:															
Columbia			92	25					26.1	0					20.5
Honey, Mo. No. 97:															
Columbia				32						0					0
Rosslyn						86						7.0			7.0
Honey, Mo. No. 133:															
Rosslyn						39						2.6			2.6
Honey, F. C. I. No. 9576:															
Brooklyn							9							0	0
Amarillo					505							1.2			1.2
From Java, S. P. I. No. 39276:															
Brooklyn							13							46.2	46.2
Dwarf from Java, S. P. I. No. 39269:															
Brooklyn							14							64.3	64.3
Amarillo					265							25.7			25.7
Rosslyn						56						25.0			25.0
White African, F. C. I. No. 1546:															
Brooklyn							60							33.3	33.3
Rosslyn						70						30.0			30.0
GRASS SORGHUMS															
Sudan grass, Mo. No. 56:															
Columbia		632	99					8.2	20.2						9.8
Sudan grass, Mo. No. 57:															
Columbia			90						8.9						8.9
Sudan grass, Mo. No. 89:															
Columbia				600						0					0
Sudan grass:															
Manhattan		500	200			152		3.2	1.0			0			2.1
Amarillo		116	165					2.6	0						1.1

Most of our sorghos came from South Africa. Leonard Wray, an English sugar planter at Natal, South Africa, procured 16 varieties of sorghos (3) grown by the various native tribes and called "Imphee." These were introduced into the United States, and in 1857 they were grown in Georgia and South Carolina. Most of the sorghos now grown in the United States except those of the Amber type have descended from this introduction. The original strains were soon widely distributed over the United States. Hybridization and selection re-

sulted in a speedy multiplication of so-called varieties. Fully 200 names have been recorded for various saccharine sorghums, although it is doubtful whether the number of actual varieties was ever more than 20.

Most of the common varieties of sorgo fall into one of the four following groups: Black Amber, Red Amber, Orange, and Sumac. Data on the infection obtained on the various strains and varieties are presented in Table 2, in which the varieties are separated into these groups.

Early Amber, the original Black Amber strain, was supposedly developed in Indiana from the first Chinese importation (1). More recently other varieties or strains have been developed, such as Minnesota Amber, Dakota Amber, Improved Amber, and Earliest Black. Folger, or Folger Early, is also a strain of the Early Amber, especially improved as a sirup variety. Collier and McLean are closely related varieties. These are, for the most part, strains or varieties selected from the original Early Amber, differing perhaps in earliness and other characteristics.

Altogether, 21 different strains of the Black Amber group of sorgos were inoculated with the spores of *Sphacelotheca sorghi*. These strains included the more or less distinct varieties of Amber sorgo, such as Dakota Amber, Minnesota Amber, Early Amber, Folger Early, Collier, and McLean. With two apparent exceptions all the strains proved susceptible, generally showing high percentages of infection.

Some of the highest infections obtained with any sorghums were obtained on strains of this group. It was not uncommon to obtain infection running above 40 per cent. It is especially interesting to note the high percentages of infection obtained at Amarillo and Manhattan with Folger Early (F. C. I. No. 1480). At Amarillo 50.8 per cent out of a total of 256 heads were infected, and at Manhattan 61.6 per cent of infection was obtained out of a total of 73 heads. These percentages of infection equal or surpass those obtained with the same or other strains at the other stations.

The varieties of the Red Amber group are very similar in growth to Black Amber but have red instead of black glumes. Five strains of the Red Amber group were grown, two under the name of Early Rose and three as Red Amber. In general, Early Rose showed a high percentage of infection, running up to 60.4 per cent in one case. Red Amber generally showed less infection than Black Amber, and 157 plants of one strain at Columbia, Mo., in 1918 showed no infection whatever. The strains at Manhattan and Amarillo showed comparatively low percentages of infection.

The Orange sorgos constitute a distinct group. They are of South African origin and can be traced to one of the Wray introductions. They differ from the Amber group in having larger and heavier stems and more abundant leaves. The panicles also are much more compact than those of Amber. Several strains have been developed, such as Kansas Orange, Late Orange, Improved Orange, and Perennial Orange. Colman is a variety which is said to have originated as a hybrid between Early Amber and Orange sorgo, but is more closely related to Orange than to Early Amber. Planter and Silver-top are closely related varieties.

The Orange group of sorgos has proved extremely susceptible to the kernel smut. Seventeen varieties and strains have been grown, and usually very high percentages of infection have been obtained. This is notably the case with one strain at Columbia and with practically all the strains grown at Brooklyn. Certain strains grown at Columbia in 1918 usually gave negative results, but the same strains at Rossllyn and Brooklyn later proved to be very susceptible. Relatively high percentages of infection were obtained with the strains grown at Amarillo and Manhattan.

A fourth group of sorgos includes the Sumac sorgo, also one of Wray's original varieties. It is sometimes called Redtop, Redtop African, Redhead, Red Liberian, or Red Imphee. It has remained true to type, while many of the other African varieties proved to be exceedingly variable.

Five strains of Sumac sorgo were used in the experiments. One strain of Dwarf Ashburn, a form similar to Sumac but with a shorter stalk, also was grown. Relatively high percentages of infection were obtained on nearly all strains grown at Columbia and Rossllyn, and especially at Brooklyn. Sumac must be classed among the more susceptible varieties of sorgo.

Other varieties which do not belong to any of these groups are Denton, Gooseneck, Honey, White African, and two importations from Java. One strain of Gooseneck showed no infection on a limited number of plants at Columbia in 1918 and Rossllyn in 1920, and another strain showed no infection at Brooklyn in 1921, although heavily infected at Manhattan that year. With the exception of one strain at Columbia in 1917, Honey sorgo has shown little or no infection. The two varieties from Java and the White African have been heavily infected in every case.

Sudan grass has proved somewhat susceptible to the covered kernel smut. Three lots were grown at Columbia; two of them gave slightly less than 10 per cent infection and the third gave negative results. The latter, however, was grown only during the season of 1918. At Amarillo, Tex., two lots were grown, and only three heads were smutted. At Manhattan, Kans., two lots were grown, and 18 out of 852 heads were infected. These results are based upon head counts rather than upon plant counts.

#### RESULTS WITH BROOMCORN

Three distinct varieties of broomcorn are grown in the United States, the principal differences being in the height of the plant, in the tenacity of the attachment of the peduncle to the upper node, and in the length and texture of the brush. One of these varieties, best known as Standard broomcorn, is grown under various names, such as Australian, California Golden, Chinese Evergreen, Early Longbrush Evergreen, Evergreen, Imperial Evergreen, Improved Evergreen, Missouri Evergreen, Tennessee Evergreen, and Wisconsin Evergreen. During the early period of broomcorn culture in the United States the Standard variety was the one grown. In recent years, as the center of production has been moved westward the Standard variety has been replaced largely by the dwarf broomcorns.

There are two varieties of dwarf broomcorn. Acme broomcorn, sometimes known as Dwarf Standard, was developed recently from a

selection of the Standard broomcorn made in 1906 by A. H. Leidigh at Channing, Tex. It resembles the Standard in the length and texture of the brush but is dwarf in stature. The second variety of dwarf broomcorn is known as Dwarf. Its exact origin is not known. Various names have been applied to it; for example, California Golden Dwarf, Dwarf, Dwarf Evergreen, Evergreen Dwarf, Japanese Dwarf, and Oklahoma Dwarf. It ranges in height from  $3\frac{1}{2}$  to 6 feet. At present this variety comprises about two-thirds of the total broomcorn crop of this country.

All three varieties of broomcorn have been used in these experiments to determine their reaction to the covered kernel smut. The data are presented in Table 3.

TABLE 3.—*Results of inoculation experiments with spores of covered kernel smut on varieties of broomcorn at five stations in one or more of the seven years from 1915 to 1921, inclusive*

Variety, strain, and station	Number of plants grown							Percentage of plants infected								
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	Average	
Acme, C. I. No. 243:																
Manhattan					90							31.1			31.1	
Brooklyn							113							37.2	37.2	
Amarillo					771							13.1			13.1	
Rossllyn						389							12.1		12.1	
Acme, C. I. No. 243-7-2:																
Manhattan		176	150	64	92			12.5	2.0	12.5	14.1				9.5	
Brooklyn							19							21.1	21.1	
Amarillo		181	34	26	372			11.0	8.8	11.5	15.1				13.4	
Rossllyn						129							13.2		13.2	
Dwarf, Mo. No. 7:																
Columbia	221							6.3							6.3	
Dwarf, C. I. No. 442:																
Manhattan		145	153	54	74			7.6	5.2	18.5	8.1				8.2	
Amarillo		170	31	72	373			8.2	3.2	9.7	20.4				15.2	
Rossllyn						60							10.0		10.0	
Standard, Mo. No. 8:																
Columbia	46							4.3							4.3	
Standard, Mo. No. 23:																
Columbia		446	109	87				24.2	31.2	1.1					22.3	
Standard, Mo. No. 24:																
Columbia		545	115	82				36.3	23.5	6.1					31.0	
Brooklyn							22							27.3	27.3	
Standard, Mo. No. 25:																
Columbia			132	63					30.3	6.3					22.6	
Standard, Mo. No. 26:																
Columbia		321	120	68				40.8	29.2	11.8					34.2	
Standard, Mo. No. 64:																
Columbia			115	66					21.7	7.6					16.6	
Brooklyn							16							12.5	12.5	
Standard, Mo. No. 71:																
Columbia				74						9.5					9.5	
Brooklyn							20							35.0	35.0	
Rossllyn						84							10.7		10.7	
Standard, Mo. No. 198:																
Brooklyn							11							45.5	45.5	
Standard, Mo. No. 199:																
Brooklyn							94							28.7	28.7	
Standard, C. I. No. 446:																
Manhattan		144	140	137	78			11.1	10.0	12.4	9.0				10.8	
Brooklyn							26							23.1	23.1	
Amarillo		173	97	55	311			5.8	12.4	18.2	12.5				11.2	
Rossllyn						78							5.1		5.1	

Acme broomcorn (C. I. No. 243) was grown one year at each of the stations except Columbia. The infection varied from 12.1 per cent at Rossllyn to 37.2 per cent at Brooklyn. A selection of Acme (C. I. No. 243-7-2) also was grown at the same stations. The average percentage of infection at Manhattan in four years was 9.5, the lowest (2 per cent) in 1917 and the highest (14.1 per cent) in 1919.

At Amarillo the average for four years was 13.4 per cent, the lowest (8.8 per cent) in 1917 and the highest (15.1 per cent) in 1919. The percentage of infection at Rosslyn in 1920 was 13.2 and at Brooklyn in 1921 21.1 per cent.

One strain of Dwarf broomcorn grown at Columbia in 1915 had 6.3 per cent infection. Dwarf broomcorn (C. I. No. 442) was grown at Manhattan in four years with an average of 8.2 per cent infection, the lowest (5.2 per cent) in 1917 and the highest (18.5 per cent) in 1918. At Amarillo the average infection of the same variety in the four years was 15.2 per cent, the lowest (3.2 per cent) in 1917, and the highest (20.4 per cent) in 1919. At Rosslyn 10 per cent of the plants grown in 1920 were infected.

Seven strains of Standard broomcorn were grown at Columbia. A total of 2,389 plants was produced, of which 630, or 26.4 per cent, were smutted. The lowest percentage of infection obtained was 1.1 in 1918 and the highest (40.8 per cent) in 1916. Standard broomcorn (C. I. No. 446) had 5.1 per cent infection at Rosslyn and 23.1 per cent at Brooklyn. It was grown during four years at Manhattan with an average of 10.8 per cent infection, the lowest being 9 per cent in 1919 and the highest (12.4 per cent) in 1918. At Amarillo the average for the same four years was 11.2 per cent, with the lowest (5.8 per cent) in 1916 and the highest (18.2 per cent) in 1918. Two additional strains were grown at Brooklyn, and 32 plants out of 105, or 30.5 per cent, were infected.

These results indicate clearly that all strains of broomcorn are moderately susceptible to the covered kernel smut.

#### RESULTS WITH KAOLIANG

The kaoliangs (5) are varieties of sorghum which are extensively grown in Manchuria and elsewhere in northeastern China, where they are used both for human food and for the feeding of farm animals. Numerous varieties were introduced into the United States between 1902 and 1908. These vary greatly in height, earliness, productiveness, and other qualities. Only one variety is now of any commercial importance in the United States. This is the Manchu, which is grown to a slight extent in South Dakota. The South Dakota Agricultural Experiment Station has made a selection of the Manchu variety and given it the name "Arco."

The kaoliangs constitute a distinct group of grain sorghums. They possess a slender dry stem, the internodes are long, and the plant bears 7 to 10 leaves. The panicle is compressed, with the glumes tightly appressed to the brown or white grains. The varieties introduced may be grouped into three classes: (1) The white kaoliangs, with white glumes and white kernels; (2) the blackhull kaoliangs, with black glumes and white kernels; and (3) the brown kaoliangs, by far the largest group, containing a great diversity of varieties, characterized by brown or reddish brown kernels and black, brown, or red glumes.

Data relating to the inoculation experiments on the various kaoliangs are presented in Table 4.

TABLE 4.—Results of inoculation experiments with spores of covered kernel smut on varieties of kaoliang at five stations in one or more of the seven years from 1915 to 1921, inclusive

Variety, strain, and station	Number of plants grown							Percentage of plants infected							Average
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	
BLACKHULL															
Barchet, Mo. No. 20: Columbia	335							31.0							31.0
Barchet, Mo. No. 61: Columbia			91	39					28.6	0					20.0
Brooklyn							18							44.4	44.4
Barchet, C. I. No. 310: Manhattan		75	24		105			13.3	12.5		49.5				31.9
Brooklyn						57								5.3	5.3
Amarillo		82	153	145	515			8.5	2.0	24.1	43.7				30.2
Rosslyn						52						36.5			36.5
WHITE															
Mukden, C. I. No. 190: Manhattan		57	71	15				12.3	7.0	0					8.4
Amarillo		36	95	29				2.8	14.7	6.9					10.6
BROWN															
Brown, Mo. No. 40: Columbia		194	114	77				10.8	14.0	5.2					10.6
Brown, S. P. I. No. 38463: Brooklyn							14							0	0
Choonehun, C. I. No. 413: Manhattan		124	127	50	104			3.2	0	0	1.9				1.5
Brooklyn						33							36.4		36.4
Amarillo		132	83	282	284			6.8	0	0	1.8				1.8
Rosslyn					63							1.6			1.6
Chusan, C. I. No. 324: Manhattan		127	190	53	115			3.9	7.9	13.2	2.6				6.2
Brooklyn						51							47.1		47.1
Amarillo		267	323	105	488			2.6	8.4	3.8	2.9				4.4
Rosslyn						77						6.5			6.5
Manchu, Mo. No. 21: Columbia	163							4.3							4.3
Manchu, Mo. No. 39: Columbia		203	108	69				24.6	27.8	4.3					21.8
Manchu, Mo. No. 58: Columbia			92	63					4.3	0					2.6
Brooklyn						10							50.0		50.0
Manchu, C. I. No. 171: Manhattan		110	125	99	103			7.3	12.8	13.1	30.1				15.6
Brooklyn						158							32.3		32.3
Amarillo		116	127	192	377			12.1	10.2	21.4	18.8				17.1
Rosslyn					58							6.9			6.9
Manchu, C. I. No. 328-1: Manhattan		136	55	103	103			6.6	18.2	28.2	37.9				21.9
Brooklyn						16							56.3		56.3
Amarillo		163	214	350	373			12.9	4.2	5.1	13.1				8.8
Rosslyn					35							2.9			2.9
Parker, C. I. No. 424: Manhattan		154	188	48	67			3.2	2.1	6.3	6.0				3.5
Amarillo		155	244	360	344			11.0	6.1	2.2	7.6				6.0
Rosslyn					41							2.4			2.4
Valley, C. I. No. 309: Brooklyn						151							61.6		61.6
Shantung Dwarf, Mo. No. 22: Columbia	276							4							4
Brooklyn						4							0		0
Shantung Dwarf, C. I. No. 293: Manhattan		134	143	167	119	103		0	7	0	0	0			2
Brooklyn						10							0		0
Amarillo		137	181	189	322			0	0	0	0				0
Rosslyn					60							0			0

Three strains of Manchu kaoliang were grown at Columbia, a total of 698 plants being obtained, of which 94, or 13.5 per cent, were infected. Manchu (C. I. No. 171) was grown four years at Manhattan and Amarillo, the average infection being 15.6 per cent and 17.1 per cent, respectively. At Rosslyn 6.9 per cent of the plants were infected and at Brooklyn 32.3 per cent. Manchu kaoliang (C. I. No. 328-1) was also grown four years at Manhattan and Amarillo, with an average infection of 21.9 per cent at the former station and 8.8 per cent at the latter. At Rosslyn 2.9 per cent of the plants were infected and at Brooklyn 56.3 per cent, the number of plants at both stations being small.

Valley kaoliang (C. I. No. 309) was grown only at Brooklyn, where 93 out of 151 plants, or 61.6 per cent, were infected.

Shantung Dwarf kaoliang<sup>9</sup> (Mo. No. 22) was grown at Columbia in 1915, and only one infected plant out of a total of 276 was recorded; at Brooklyn only four plants were obtained, none of which was infected. Shantung Dwarf kaoliang (C. I. No. 293) was grown five years at Manhattan and four at Amarillo. In a total of 1,495 plants grown at the two stations only one infected plant was recorded. The same strain at Rosslyn and Brooklyn gave no infected plants. Possibly the infected plants at Columbia and Manhattan were not actually of this variety; in any case, Shantung Dwarf is very resistant to covered kernel smut.

Two strains of Barchet blackhull kaoliang were grown at Columbia. Missouri No. 20 was grown in 1915, and 31 per cent of the plants were infected. Missouri No. 61 was grown in 1917 and 1918. In 1917, 28.6 per cent of the plants were infected, but in 1918 negative results were obtained. The same strain was grown at Brooklyn, where 44.4 per cent of the plants were infected. Barchet kaoliang (C. I. No. 310) was grown at Manhattan three years, where an average infection of 31.9 per cent was obtained, and at Amarillo four years, the average infection being 30.2 per cent. At Rosslyn 36.5 per cent of the plants were infected, while at Brooklyn only 5.3 per cent showed smut.

Mukden white kaoliang (C. I. No. 190) was grown three years at both Manhattan and Amarillo, with an average of 8.4 per cent infection at the former station and 10.6 per cent at the latter.

Brown kaoliang (Mo. No. 40) was grown three years at Columbia, with an average infection of 10.6 per cent. Chusan kaoliang (C. I. No. 324) was grown during four years at Manhattan and Amarillo, with an average infection of 6.2 per cent and 4.4 per cent, respectively; at Rosslyn 6.5 per cent of the plants were infected and at Brooklyn 47.1 per cent. Choonchun kaoliang (C. I. No. 413) also was grown four years at Manhattan and Amarillo, with average infections of 1.5 per cent and 1.8 per cent, respectively; at Rosslyn 1.6 per cent infection was obtained and at Brooklyn 36.4 per cent. Parker kaoliang (C. I. No. 424) showed a 4-year average infection of 3.5 per cent at Manhattan and 6 per cent at Amarillo; at Rosslyn, 2.4 per cent of the plants were infected. Brown kaoliang (S. P. I. No. 38463) was grown at Brooklyn, but only 14 plants were obtained, none of which was infected.

<sup>9</sup> This so-called dwarf kaoliang (C. I. No. 293 and S. P. I. 22010) is different from the rest of the kaoliang group, according to C. R. Ball, and probably represents either a selection or a hybrid from one of the near durras from India.

From the results it is evident that one variety of kaoliang, Shantung Dwarf, is very resistant to covered kernel smut. Manchu kaoliang, on the other hand, is very susceptible. The other brown kaoliangs showed considerable evidence of resistance except at Brooklyn, where the percentage of infection was high. Barchet proved rather susceptible and Mukden only moderately resistant. As a group, the kaoliangs are not so susceptible as the kafirs or sorgos.

#### RESULTS WITH KAFIR

The kafirs (3, 7) were first introduced into the United States from southeastern Africa in 1876. At that time two varieties, White kafir and Red kafir, were exhibited by the then Orange Free State at the Philadelphia exposition. These were grown in Georgia for several years and thence distributed to the southern Great Plains area. Recently a number of additional varieties have been introduced from southern Africa.

The kafirs are the latest of the grain sorghums commonly grown in the United States. They are distinguished from other groups by their stout, stocky, semijuicy stems with short internodes and overlapping leaf sheaths. Six varieties are grown, all commonly but the White. These are White, Blackhull, Dawn, Sunrise, Pink, and Red. White kafir was one of the earliest introductions. It is rather dwarf in stature and is the earliest of all the kafirs. The glumes and seeds are white. It has very largely passed out of cultivation, although it was grown extensively some years ago. Its chief value is its earliness.

The exact origin of Blackhull kafir is not known. It may have been brought with the first introduction of kafirs from southeastern Africa. It has been grown more extensively than any other kafir, as it succeeds well in most of the Great Plains area. It is characterized by black glumes and white seeds.

Sunrise and Dawn kafirs originated from a single head selected in the autumn of 1906 in a field of Blackhull kafir by A. H. Leidigh, then superintendent of the Amarillo Field Station. The seed of this head was sown the next season. From the resulting crop, selections were made by Ball (7), from two of which Sunrise and Dawn kafirs were developed. Both resemble Blackhull kafir, but mature earlier, while Dawn is dwarfed. While the exact parentage of the original head from which these varieties have been developed is not known, the earliness, variable stature, and scarcely exerted heads and smaller kernels of the progeny indicate hybridization with White kafir.

Pink kafir, probably the result of a natural cross between White and Red, was found growing in Kansas about 1905. It also has been introduced direct from Africa (S. P. I. No. 19742), whence it was sent to Chillicothe, Tex., in 1908 and grown there. It is characterized by pink seeds and white glumes and is somewhat later than White, which it resembles in manner of growth. The heads are rather intermediate in length and shape between those of Red and Blackhull.

Red kafir was introduced from Africa at the same time as White. The seeds are red and the glumes are dark red to black. While it was formerly grown to some extent, it has now been replaced largely by the Blackhull and other varieties which usually produce higher yields.

The results of the inoculation experiments with kafir are shown in Table 5.

TABLE 5.—*Results of inoculation experiments with spores of covered kernel smut on varieties of kafir at five stations in one or more of the seven years from 1915 to 1921, inclusive*

Variety, strain, and station	Number of plants grown							Percentage of plants infected										
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	Average			
Blackhull, Mo. No. 2:																		
Columbia	290							19.3									19.3	
Brooklyn							7							85.7			85.7	
Blackhull, Mo. No. 17:																		
Columbia	304							15.8									15.8	
Blackhull, Mo. No. 33:																		
Columbia		178	112	95				53.9	68.8	7.4							46.8	
Blackhull, Mo. No. 34:																		
Columbia		191	106	49				44.5	68.9	2.0							46.0	
Blackhull, Mo. No. 35:																		
Columbia			121						51.2								51.2	
Blackhull, Mo. No. 69:																		
Columbia			99						57.6								57.6	
Blackhull, Mo. No. 73:																		
Columbia				31							12.9						12.9	
Brooklyn							11								27.3		27.3	
Rosslyn							20							15.0			15.0	
Blackhull, Mo. No. 85:																		
Columbia				82							18.3						18.3	
Brooklyn							16								25.0		25.0	
Rosslyn							46							13.0			13.0	
Blackhull, Mo. No. 203:																		
Brooklyn							58								19.0		19.0	
Blackhull, C. I. No. 71:																		
Manhattan		136	213	51	80	108		7.4	2.8	43.1	25.0	3.7					10.5	
Brooklyn							62								19.4		19.4	
Amarillo		98	161		225			12.2	8.1			16.0					12.6	
Rosslyn						30							0				0	
Blackhull, C. I. No. 204:																		
Manhattan					103	118						41.7	9.3				24.4	
Brooklyn							36								61.1		61.1	
Amarillo					319							26.0					26.0	
Rosslyn						469							33.0				33.0	
Blackhull, C. I. No. 207:																		
Manhattan		95	97	59	151	94	121	12.6	9.3	23.7	30.5	10.6	7.4				16.2	
Amarillo		80	107	18	587			3.8	15.9	5.6	22.5						19.3	
Rosslyn						19							21.1				21.1	
Blackhull, F. C. I. No. 2026:																		
Brooklyn							53								45.3		45.3	
Blackhull (Africa), C. I. No. 321:																		
Manhattan		104	163	131	67			14.4	14.7	22.9	64.2						24.1	
Brooklyn							17								41.2		41.2	
Amarillo		136	250		197			8.8	11.2		51.3						24.2	
Rosslyn						59							3.4				3.4	
Blackhull Dwarf, C. I. No. 628:																		
Brooklyn							90								51.1		51.1	
Dawn, Mo. No. 18:																		
Columbia	117							16.2									16.2	
Dawn, C. I. No. 340:																		
Manhattan		157	12	48	111	122	81	13.4	8.3	27.1	18.0	8.2	13.6				14.3	
Brooklyn							60								43.3		43.3	
Amarillo		84	184	44	752			21.4	28.4	43.2	13.6						17.1	
Rosslyn						565							42.3				42.3	
Dawn, F. C. I. No. 1932:																		
Brooklyn							41								36.6		36.6	
Progressive:																		
Manhattan					55	122	11					23.6	3.3	18.2			10.1	
Sunrise, C. I. No. 472:																		
Manhattan		137	50	107	125	175		6.6	6.0	39.3	36.0	21.1					22.9	
Brooklyn							178								39.3		39.3	
Amarillo		98	136	49	535			13.3	13.2	42.9	23.4						21.6	
Rosslyn						531							29.2				29.2	
White, Mo. No. 19:																		
Columbia	204							9.3									9.3	
White, C. I. No. 252:																		
Manhattan		74	85	65	64			12.2	15.3	33.8	42.2						24.7	
Amarillo		76	74	2	159			2.6	10.8	0	24.5						15.8	
White (African), C. I. No. 314:																		
Manhattan		113	103	140	112			14.2	25.2	18.6	28.6						21.4	
Brooklyn							39								17.9		17.9	
Amarillo		144	125	22	381			11.8	32.0	22.7	19.7						20.4	
Rosslyn						61							31.1				31.1	

TABLE 5.—Results of inoculation experiments with spores of covered kernel smut on varieties of kafir at five stations in one or more of the seven years from 1915 to 1921, inclusive—Continued

Variety, strain, and station	Number of plants grown							Percentage of plants infected							Average
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	
Pink, Mo. No. 37:															
Columbia			134	52						76.9	25.0				62.3
Brooklyn							17							64.7	64.7
Pink, Mo. No. 94:															
Columbia				55						32.7					32.7
Rosslyn						50						14.0			14.0
Pink, C. I. No. 432:															
Manhattan		105	8	101	113			12.4	37.5	44.6	59.3				39.1
Amarillo		124	234	31	694			12.9	14.1	29.0	30.8				25.1
Rosslyn						27						18.5			18.5
Pink, Kansas station:															
Manhattan				66	43					22.7	39.5				29.4
Amarillo					115						29.6				29.6
Pink, F. C. I. No. 1930:															
Brooklyn							29							31.0	31.0
Pink (late), F. C. I. No. 9439:															
Brooklyn							64							43.8	43.8
Pale Red, C. I. No. 316:															
Manhattan		95	173	26	141	131		14.7	28.9	42.3	38.3	34.4			30.7
Brooklyn							10						50.0		50.0
Amarillo		74	107		415			6.8	33.6		23.9				23.5
Rosslyn						21						14.3			14.3
Red, Mo. No. 1:															
Columbia	229							16.6							16.6
Red, Mo. No. 36:															
Columbia		318	100	47				36.2	49.0	10.6					36.3
Brooklyn							8						37.5		37.5
Red, Mo. No. 80:															
Columbia				55						7.3					7.3
Brooklyn							8					25.0			25.0
Rosslyn						37						35.1			35.1
Red, Mo. No. 90:															
Columbia				26						15.4					15.4
Brooklyn							11					36.4			36.4
Rosslyn						28						14.3			14.3
Red, Mo. No. 202:															
Brooklyn							32							18.8	18.8
Red, Kansas station:															
Manhattan					92						34.8				34.8
Red, C. I. No. 34:															
Manhattan		107	175	135	121			16.8	9.1	23.0	39.7				21.0
Brooklyn							55						65.5		65.5
Amarillo		112	78	2	307			9.8	3.8	0	26.7				19.2
Rosslyn						459						54.7			54.7
Red, C. I. No. 323:															
Brooklyn							33							24.2	24.2

Eight different strains of Blackhull kafir were grown at Columbia, and all proved to be highly susceptible. A total of 1,658 plants was obtained, 581, or 35 per cent, showing infection. Three of the same strains were grown at Brooklyn, 13 out of 34 plants, or 38.2 per cent, being infected. Blackhull kafir (C. I. No. 71) was grown five years at Manhattan, the average infection being 10.5 per cent. It was also grown three years at Amarillo, where the average percentage of infection was 12.6. At Rosslyn it gave negative results, while at Brooklyn 19.4 per cent of the plants were infected. Blackhull kafir (C. I. No. 204) was grown two years at Manhattan, the average percentage of infection being 24.4. At Amarillo 26 per cent of the plants were infected, at Rosslyn 33 per cent, and at Brooklyn 61.1 per cent. Blackhull kafir (C. I. No. 207), grown six years at Manhattan, showed an average infection of 16.2 per cent, while the 4-year average at Amarillo was 19.3 per cent. At Rosslyn 21.1 per cent of the plants were infected. Blackhull kafir (F. C. I. No. 2036) grown at Brooklyn showed 45.3 per cent infection. Black-

hull (Africa, C. I. No. 321) was grown four years at Manhattan and three years at Amarillo, the average infection being 24.1 per cent and 24.2 per cent, respectively. At Rosslyn 3.4 per cent and at Brooklyn 41.2 per cent of infection occurred. Blackhull Dwarf (C. I. No. 628) was grown only at Brooklyn, where it showed 51.1 per cent of infection.

One strain of Dawn kafir was grown at Columbia in 1915, 16.2 per cent of the plants being infected. Dawn kafir (C. I. No. 340) was grown at Manhattan six years and at Amarillo four years, the average infection at the former station being 14.3 per cent and at the latter 17.1 per cent. At Rosslyn 42.3 per cent and at Brooklyn 43.3 per cent of the plants were infected. Dawn kafir (F. C. I. No. 1932) grown at Brooklyn showed 36.6 per cent infection.

Sunrise kafir (C. I. No. 472) was grown five years at Manhattan and four at Amarillo, the average infection being 22.9 per cent and 21.6 per cent, respectively. At Rosslyn 29.2 per cent of infection and at Brooklyn 39.3 per cent was obtained.

A strain of White kafir was grown for one season at Columbia, 9.3 per cent of the plants being infected. White kafir (C. I. No. 252) was grown four years at Manhattan and Amarillo. At the former station the average infection was 24.7 per cent and at the latter 15.8 per cent. White African kafir (C. I. No. 314) also was grown four years at both Manhattan and Amarillo, the infection percentages being 21.4 and 20.4, respectively. At Rosslyn 31.1 per cent and at Brooklyn 17.9 per cent of the plants were infected.

Two strains of Pink kafir were grown at Columbia, Missouri No. 37 for two years and Missouri No. 94 one year. The former showed 62.3 per cent infection and the latter 32.7 per cent. Pink kafir (C. I. No. 432) was grown at Manhattan and Amarillo four years, with average infections of 39.1 per cent and 25.1 per cent, respectively. At Rosslyn 18.5 per cent infection was obtained. A Pink kafir from the Kansas station was grown two years at Manhattan and one year at Amarillo. At Manhattan 32 out of a total of 109 plants, or 29.4 per cent, were infected; at Amarillo an infection of 29.6 per cent was obtained. Pink kafir (F. C. I. No. 1930) was grown at Brooklyn, where an infection of 31 per cent was recorded. Late Pink kafir (F. C. I. No. 9439) at Brooklyn showed 43.8 per cent infection.

Pale Red kafir (C. I. No. 316) was grown five years at Manhattan and three at Amarillo, showing 30.7 per cent and 23.5 per cent of infection, respectively. At Rosslyn 14.3 per cent and at Brooklyn 50 per cent of the plants were infected, the number of plants in each case being small.

Four strains of Red kafir were grown at Columbia, 215 plants out of a total of 775, or 27.7 per cent, being infected. Red kafir (C. I. No. 34) was grown four years at Manhattan and Amarillo, the average infection at the former station being 21 per cent and at the latter 19.2 per cent. At Rosslyn 54.7 per cent of the plants were infected and at Brooklyn 65.5 per cent. A Kansas station strain of Red kafir at Manhattan showed 34.8 per cent infection in 1919. At Brooklyn a strain (Missouri No. 202) showed 18.8 per cent infection and C. I. No. 323, 24.2 per cent.

These results clearly indicate that all the varieties of kafir are very susceptible to covered kernel smut.

## RESULTS WITH DURRA

Apparently the durras (3, 7) were introduced into the United States from the Barbary States of northern Africa, where the leading variety of sorghum is a white durra called bechna, or beshna, by the Cabyles of Algeria. It is practically identical with the variety introduced into this country as White Egyptian corn. A very similar white durra is found throughout Turkestan, Mesopotamia, Syria, and Arabia. A red-seeded durra, very similar to our Brown durra and probably the original form of it, also is found among the mountain tribes of Algeria and in certain parts of the northern Sahara. This variety, however, has not been found in Arabia or elsewhere in southwestern Asia. In India many varieties somewhat distantly related to our durras are grown. They constitute the principal varieties of kharif jowar, or the monsoon sorghum crop, which is sown in June or July and harvested in October or November.

TABLE 6.—Results of inoculation experiments with spores of covered kernel smut on varieties of durra at five stations in one or more of the seven years from 1915 to 1921, inclusive

Variety, strain, and station	Number of plants grown							Percentage of plants infected							Average
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	
Brown, Mo. No. 30:															
Columbia		289	110	59				54.0	38.2	13.6					45.0
Brown, Mo. No. 74:															
Columbia				85						0					0
Brooklyn						10							50.0		50.0
Rosslyn						30							10.0		10.0
Brown, C. I. No. 183:															
Manhattan		32	127	148	68			18.8	7.1	8.8	25.0				12.0
Amarillo		34	133	137	259			8.8	11.3	30.7	10.4				15.5
Brown, C. I. No. 246:															
Manhattan		38	86	100	69			36.8	12.8	48.0	33.3				32.8
Amarillo		13	200	107	385			30.8	49.5	37.4	27.8				35.5
Brown, S. P. I. No. 17537:															
Manhattan		147	165	43	73			13.6	4.8	30.2	8.2				11.0
Amarillo		19	229	103	301			10.5	3.1	26.2	12.6				11.3
White, Mo. No. 6:															
Columbia	200							0							0
White, Mo. No. 16:															
Columbia	116							8.6							8.6
Brooklyn							8						50.0		50.0
White, Mo. No. 32:															
Columbia		267	88	101				37.1	3.4	0					22.4
White, Mo. No. 200:															
Brooklyn						31							41.9		41.9
White, C. I. No. 81:															
Manhattan		74	165	48	34	101		14.9	10.3	25.0	52.9	12.9			16.8
Brooklyn							29						82.8		82.8
Amarillo		65	391	203	278			9.2	9.7	2.5	46.4				19.0
Rosslyn						18						22.2			22.2
White, C. I. No. 437:															
Manhattan		63	60	116	101			9.5	0	1.7	2.0				2.9
Amarillo		33	171	198	332			0	.6	1.0	.9				.8
White, C. I. No. 529:															
Manhattan		74	76					0	1.3						.7
Amarillo		81	362					0	.3						.2
White, S. P. I. No. 14518:															
Manhattan		31	14					0	0						0
Amarillo		5	30	49				0	6.7	12.2					9.5
White, S. P. I. No. 14628:															
Manhattan		140	158	71				0	0	0					0
Amarillo		48	438		202			0	0		.5				.1
White, S. P. I. No. 17535:															
Manhattan		153	76	84	96			27.5	3.9	33.3	14.6				21.3
Amarillo		60	324	115	518			10.0	15.4	39.1	16.4				18.3
White, S. P. I. No. 38592:															
Manhattan		54	18	56	68			13.0	16.7	16.1	4.4				11.2
Amarillo		30	216	22	87			6.7	2.8	9.1	0				2.8

The durras now grown in the United States constitute a group of the grain sorghums closely related to *feterita* and the milos. They are characterized by slender to midstout dry, pithy stems. The panicles are short, broadly ovate or oval, and compact. The glumes are greenish white, densely pubescent, and not transversely wrinkled. The seeds are very much flattened.

Two varieties of durra are grown in the United States—White durra, with white seeds and awned lemmas, and Brown durra, with brown seeds and awnless lemmas. White durra was introduced into California about 1874, where it is commonly known as White Egyptian corn. A few years later this durra was grown to some extent in the southern Great Plains States under the name of Jerusalem corn. Brown durra has frequently been known as Brown Egyptian corn, but it has never been agronomically important. Data from the infection experiments with the durras are presented in Table 6.

Two strains of Brown durra were grown at Columbia. One strain (Missouri No. 30), grown during three years, showed an average infection of 45 per cent. A second strain (Missouri No. 74), grown in 1918, gave negative results, but the same strain showed 10 per cent infection at Rosslyn and 50 per cent at Brooklyn. Brown durra (C. I. No. 183) was grown four years at Manhattan and Amarillo, the average at Manhattan being 12 per cent and at Amarillo 15.5 per cent. Brown durra (C. I. No. 246) was also grown four years at both Manhattan and Amarillo, the average infection being 32.8 per cent and 35.5 per cent, respectively. Brown durra (S. P. I. No. 17537) was grown four years at Manhattan and Amarillo, with an average infection at the former station of 11 per cent and of 11.3 per cent at the latter.

Three strains of White durra were grown at Columbia. Negative results were obtained on one of them in 1915, while another showed 8.6 per cent infection. The third had a 3-year average infection of 22.4 per cent. White durra (C. I. No. 81) was grown for five years at Manhattan with an average infection of 16.8 per cent and for four years at Amarillo with an average infection of 19 per cent. It also was grown at Rosslyn, where it showed 22.2 per cent infection, and at Brooklyn with 82.8 per cent infection. Another strain (Missouri No. 200) at Brooklyn showed 41.9 per cent infection.

In addition to these strains of the common Brown and White durras a number of other strains of White durra were grown at Manhattan and Amarillo.

White durra (S. P. I. No. 14518) received from the Bombay Presidency, India, showed 9.5 per cent infection at Amarillo during three seasons and no infection at Manhattan in two seasons. This is a very tall strain which appears to have little agronomic value.

Another White durra (S. P. I. No. 14628) received from the Bombay Presidency has proved to be practically free from kernel smut, only one plant in 688 having been found to be infected at Amarillo during three seasons and has produced no smut in 369 plants at Manhattan in three seasons. This strain seems to have no special agronomic value.

On the other hand, White durra (S. P. I. No. 17535) from India has proved quite susceptible to the kernel smut. It was grown for four years at both Manhattan and Amarillo. At Manhattan 21.3 per cent of the plants were infected and at Amarillo 18.3 per cent.

This durra is more promising agronomically than either of the two previously mentioned.

A White durra (C. I. No. 529; S. P. I. No. 24305) received from Limavida, Chile, has proved practically free from kernel smut, only one smutted plant being recorded at Amarillo and one at Manhattan, where it was grown two seasons. It is a typical White durra, with compact ovoid heads, pithy stems, few leaves, and slightly flattened white seeds.

A White durra (C. I. No. 437; S. P. I. No. 28995) received from Merv, Turkestan, has proved very slightly susceptible to the kernel smut. Meyer mentions it as a good quality of djugara grown by the natives. It does not seem to possess any special value for either forage or grain in the United States. This strain was grown during four years at both Manhattan and Amarillo. At the former station 2.9 per cent of the plants were infected and at Amarillo less than 1 per cent.

White durra (S. P. I. No. 38592) obtained from Gizeh, Egypt, also has proved somewhat susceptible to the kernel smut. It was grown four years at both Manhattan and Amarillo. At Manhattan 11.2 per cent of the plants were infected and at Amarillo 2.8 per cent. This durra appears to be of little agronomic value.

Altogether, five strains of Brown durra were grown in the course of the experiments, and all proved susceptible. Strains of Missouri No. 30 and C. I. No. 246 showed the highest percentages of infection. Five strains of the common White durra were grown, and with one exception, the Missouri No. 6 grown in 1915 at Columbia, showed some infection. Of the six recently introduced white durras, three (S. P. I. Nos. 14628, 24305, and 28995) show marked resistance. While these do not appear to possess characteristics which fit them to compete with other sorghums in this country, yet their resistance to covered kernel smut may make them of some value in hybridization experiments with a view to combining this resistance with desirable agronomic characters.

#### RESULTS WITH MILO AND FETERITA

Milo (3, 7) was first noted in this country soon after 1880. It was grown to a considerable extent in South Carolina and Georgia and was widely advertised by a seed firm in Atlanta in the spring of 1887. Soon afterwards it was introduced into western Texas and the drier sections of adjacent States. Milo has proved to be a successful crop in the Great Plains area, because it produces grain and forage under conditions where corn and other crops fail. As a result, the acreage has steadily increased. In the Southern States, however, where milo was first grown, the crop has not been able to compete with corn.

Milo has mid-sized pithy stems, which grow 5 to 8 feet tall; short narrow leaves; large ovoid, compact, and often pendent heads; and large yellow or white somewhat flattened seeds. The original milo, grown in western Texas under the old name of Giant milo, has been improved greatly by selection. The improved varieties combine the earliness and drought resistance of the Giant milo with uniformity of height and ripening.

There are four distinct varieties of milo: Standard Yellow, Dwarf Yellow, Standard White, and Dwarf White. Standard Yellow milo is the direct descendant of the milo first introduced into this country. It has been much improved through selection for shorter stalks and earlier maturity. Dwarf Yellow milo is a selection from the Standard Yellow. It is 12 to 18 inches shorter than Standard Yellow and yields better when grown under dry conditions and at high altitudes.

Standard White milo is similar to Standard Yellow except that the seeds are creamy white, usually shading into yellowish pink at the tip, while those of the Standard Yellow are yellowish pink throughout. It possesses no special advantage over Standard Yellow and does not compare favorably with Dwarf Yellow in yield. Dwarf White milo bears the same relation to Standard White milo that Dwarf Yellow milo does to Standard Yellow. It appeared under cultivation a few years ago on the plains of Texas and Oklahoma and is well adapted to the conditions there. The results of experiments on the milos are given in Table 7.

TABLE 7.—Results of inoculation experiments with spores of covered kernel smut on varieties of milo and feterita at five stations in one or more of the seven years from 1915 to 1921, inclusive

Variety, strain, and station	Number of plants grown							Percentage of plants infected										Average
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921				
MILo																		
Dwarf White: Manhattan						131							0				0	
Dwarf White, Mo. No. 205: Brooklyn							13							0			0	
Standard White, Mo. No. 43: Columbia		200	81	164					0	0	0						0	
Standard White, Mo. No. 44: Columbia			97							0							0	
Standard White, Mo. No. 86: Columbia				111							.9						.9	
Rosslvn						50							0				0	
Standard White, C. I. No. 352: Manhattan		107	167	129	68	149	80		0	0	.8	0	0	0			.1	
Brooklyn							63							0			0	
Amarillo		92	268	43	291				1.1	0	0	0					.1	
Rosslvn						45							0				0	
Standard White, F. C. I. No. 5886: Brooklyn							51							0			0	
Dwarf Yellow, Mo. No. 14: Columbia		200						0									0	
Brooklyn							15							0			0	
Dwarf Yellow, Mo. No. 41: Columbia			93	131						0	0						0	
Dwarf Yellow, Mo. No. 42: Columbia		200	94	105					0	0	0						0	
Dwarf Yellow, Mo. No. 42a: Columbia		275	87	95					0	0	0						0	
Dwarf Yellow, Mo. No. 63: Columbia			93	79						0	0						0	
Dwarf Yellow, Mo. No. 67: Columbia			95	57						0	0						0	
Brooklyn							7							0			0	
Dwarf Yellow, Mo. No. 68: Columbia			79	119						0	0						0	
Dwarf Yellow, Mo. No. 87: Columbia				68							0						0	
Brooklyn							29							0			0	
Rosslvn						52							0				0	
Dwarf Yellow, Mo. No. 95: Columbia				42							0						0	
Rosslvn						56							0				0	
Dwarf Yellow, Mo. No. 204: Brooklyn							18								0		0	

TABLE 7.—*Results of inoculation experiments with spores of covered kernel smut on varieties of milo and feterita at five stations in one or more of the seven years from 1915 to 1921, inclusive—Continued*

Variety, strain, and station	Number of plants grown							Percentage of plants infected							Average
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	
MILO—continued															
Dwarf Yellow, C. I. No. 332:															
Manhattan		158	154	97	92		89	0	0	0	0		0		0
Brooklyn														0	0
Amarillo		91	397	133	442			0	0	0	0				0
Rosslyn						555							0		0
Dwarf Yellow, F. C. I. No. 1933:															
Brooklyn							9							0	0
Dwarf Yellow, Kansas station:						143	80						0	0	0
Manhattan															
Standard Yellow, Mo. No. 13:															
Columbia	200							0							0
Standard Yellow, Mo. No. 75:															
Columbia				66						0					0
Brooklyn						22							0		0
Rosslyn						22							0		0
Standard Yellow, Mo. No. 81:															
Columbia				94						0					0
Brooklyn						42							0		0
Rosslyn						65							0		0
Standard Yellow, Mo. No. 96:															
Columbia				95						0					0
Brooklyn						14							0		0
Rosslyn						45							0		0
Standard Yellow, C. I. No. 234:															
Manhattan		152		130	43			0		0	0				0
Brooklyn						100							0		0
Amarillo		56	292	114	264			0	0	0	0				0
Rosslyn						52							0		0
Standard Yellow, Hays, Kans.:															
Manhattan						126	80						0	0	0
FETERITA															
Mo. No. 12:															
Columbia	200							0							0
Brooklyn							11						0		0
Mo. No. 27:															
Columbia			103	64						1.0	0				.6
Brooklyn							12						8.3		8.3
Mo. No. 28:															
Columbia		230	88	72				.9	1.1	0					.8
Mo. No. 29:															
Columbia			188							.5					.5
Mo. No. 72:															
Columbia				116							0				0
Mo. No. 83:															
Columbia				77							0				0
Mo. No. 201:															
Brooklyn							10						10.0		10.0
C. I. No. 182:															
Manhattan		95	115	73	111	236	80	0	0	0	0	0	0	0	0
Brooklyn							64						0		0
Amarillo		19	279		464			0	0			0			0
F. C. I. No. 1931:															
Brooklyn							29						0		0
Dwarf, F. C. I. No. 811:															
Brooklyn							57						0		0
Spur, Texas station No. 3232:															
Manhattan					107							0			0
Brooklyn							94						0		0
Amarillo					367							0			0
Spur, C. I. No. 623:															
Manhattan						197	80						0	0	0

One strain of Dwarf White milo was grown at Manhattan in 1920. (Table 7.) No smutted plants were found in a total of 131. Another strain of this milo was grown at Brooklyn in 1921. Only 13 plants matured, none of which was smutted.

Three strains of Standard White milo were grown at Columbia; only one plant out of a total of 653 was infected. Standard White milo (C. I. No. 352) was grown six years at Manhattan and four years at Amarillo. At Manhattan one plant out of a total of 700 was infected and at Amarillo one plant out of 694. Two different strains were grown at Brooklyn and at Rosslyn, but no infected plants were obtained in totals of 114 at Brooklyn and 95 at Rosslyn.

Out of a total of 2,256 plants of Standard White milo grown at the various stations, only three infected plants were observed—one at Columbia, one at Manhattan, and one at Amarillo. The smutted plants at Columbia and Manhattan may have belonged to some other susceptible variety of sorghum. An uninfected plant of other varieties was occasionally found in the rows, but this was easily recognized and removed. The smutted plants, however, could not be identified positively.

There seems to be no doubt that the infected plant at Amarillo was Standard White milo. Only a portion of the head on this plant was infected. A few sound kernels were obtained and sown the following season, all of which developed typical Standard White milo plants (Pl. X, fig. 2).

Nine strains of Dwarf Yellow milo were grown at Columbia. A total of 1,912 plants was obtained, none of which was infected. Some of these strains were grown also at Rosslyn and Brooklyn, with the same results. Dwarf Yellow milo (C. I. No. 332) was grown four years at Manhattan and Amarillo, with a total of 1,564 plants. At Rosslyn 555 plants and at Brooklyn 89 plants of this strain were grown. At Manhattan 223 plants of a strain from the Kansas station were grown in 1920 and 1921. In no case did any infection occur.

Four strains of Standard Yellow milo were grown at Columbia, with a total of 455 plants. Standard Yellow milo (C. I. No. 234) was grown three years at Manhattan and four at Amarillo, a total of 1,051 plants being grown at the two stations. At Manhattan a strain from Hays, Kans., also was grown two years, with a total of 206 plants. At Brooklyn 178 plants of different strains were grown and at Rosslyn 184 plants. No infection appeared in any of these experiments.

It is very evident that all the milos grown possess remarkable qualities of resistance to the covered kernel smut. At all five of the stations a total of 4,529 plants of Dwarf Yellow milo was grown and no smut observed. (Table 7.) In view of these results the data reported by Kulkarni (64) are not only interesting but worthy of further consideration.<sup>10</sup> Kulkarni obtained seed of Dwarf Yellow

<sup>10</sup> Since this manuscript was prepared, one of the kernel smuts was reported as occurring in yellow milo in two localities in Texas and one in Kansas in 1923. B. F. Barnes, superintendent of the Colby Branch Station, Colby, Kans., found a few infected heads in Dwarf Yellow milo at that station. E. W. Thomas, county agent, Plainview, Tex., found a few smutted plants of the same variety in one field in Hale County, Tex. H. J. Clemmer, of the Dalhart Field Station, Dalhart, Tex., reported the occurrence of kernel smut in several fields of milo in that locality. He found 11 per cent of the heads infected in a part of one field. Samples of the smut and of the milo from these localities have been examined by members of the staff of the Office of Cereal Investigations and of the Kansas Agricultural Experiment Station and the identifications verified.

milo from the United States Department of Agriculture and after inoculation with spores of *Sphacelotheca sorghi* and *S. cruenta* sowed it on the Agricultural College Farm at Poona, India. Apparently the same lot of seed was inoculated with the spores of both smuts. A total of 645 heads was obtained, of which three were infected by *S. sorghi* (0.47 per cent infection) and 50 by *S. cruenta* (7.8 per cent infection). The three plants infected by *S. sorghi* may have been some other sorghum, but the rather high percentage of infection with *S. cruenta* scarcely can be thus explained. Possibly Dwarf Yellow milo is susceptible to *S. cruenta*, although Potter (91) and Reed (97) have reported negative results.

Feterita was imported into the United States in 1901 from Alexandria, Egypt. A second importation was made in 1906, also from Alexandria, although the seed originally came from the Sudan. In 1908 an additional supply was obtained from Khartum, Sudan, where it was known as Sudan durra.

Feterita is similar to milo in most of the characters of the stalks and leaves. Under Texas Panhandle conditions it averages about 5 feet high, or about 1 foot taller than Dwarf Yellow milo. The panicles are erect, the seeds chalky or bluish white, and the glumes dark brown to black. Since its introduction it has been improved by selection and for some sections is a desirable sorghum. Dwarf feterita is a selection from the improved strain made by H. N. Vinall in 1909. The plant originally selected was only 2½ feet high and was fully mature two weeks earlier than the general crop. This strain has not fully retained either its dwarfness or its earliness. Spur feterita is a strain developed at the Spur substation in Texas.

Twelve different strains of feterita, including Dwarf feterita and Spur feterita, have been grown in the smut experiments at the various stations. (Table 7.) These have all proved to be strikingly resistant to the covered kernel smut. No infections have been noted in a total of 1,472 plants of C. I. No. 182 grown during three years at Amarillo and six years at Manhattan. Six different strains were grown at Columbia. Out of a total of 1,138 plants 5 were recorded as infected. As mixtures sometimes occurred, possibly the smutted plants were other varieties of sorghums present in the rows which could not be identified. Out of 277 plants grown at Brooklyn, 2 were smutted. There seemed to be no question about the identity of these smutted heads, for some seeds developed in both cases which were typical feterita. In any case feterita has been shown to be very resistant to the kernel smut, and the results verify the frequent observations that have been made as to the freedom of this sorghum from smut in the field.

#### RESULTS WITH MISCELLANEOUS SORGHUMS

A number of additional sorghums, for the most part hybrids between various members of the commonly recognized groups, have been grown in these experiments. Data from the inoculation experiments on these sorghums are presented in Table 8.

TABLE 8.—*Results of inoculation experiments with spores of covered kernel smut on varieties of miscellaneous sorghums at five stations in one or more of the seven years from 1915 to 1921, inclusive*

Variety, strain, and station	Number of plants grown							Percentage of plants infected							Average
	1915	1916	1917	1918	1919	1920	1921	1915	1916	1917	1918	1919	1920	1921	
BROOMCORN X SORGO															
Amber Saccharine, C. I. No. 619: Manhattan					74							25.7			25.7
Golden Saccharine, C. I. No. 618: Manhattan					39							12.8			12.8
DARSO															
Mo. No. 49: Columbia		200	108	19					0	0	0				0
Brooklyn							12							0	0
C. I. No. 615: Manhattan							80							0	0
FREED SORGHUM															
Mo. No. 51: Columbia		338	100						4.4	8.0					5.3
Brooklyn							6							33.3	33.3
S. P. I. No. 29166: Manhattan		17	50		71				5.9	0		14.1			8.0
Brooklyn							6							33.3	33.3
Amarillo		25	48		637				4.0	0		29.2			26.3
Roslyn						76							5.3		5.3
C. I. No. 350: Manhattan						688	80						0	0	0
DWARF HEGARI															
Mo. No. 45: Columbia		200	99	67					0	0	0				0
Mo. No. 84: Columbia				98							0				0
Roslyn						22						0			0
S. P. I. No. 34911: Manhattan							80							0	0
Brooklyn							10							0	0
HUSSERITA															
Hays, Kans: Manhattan						221	26						5.4	7.7	5.7
KAFIRITA															
C. I. No. 548: Manhattan						97	80						0	0	0
SCHROCK SORGHUM															
Mo. No. 38: Columbia			101	82					40.6	8.5					26.2
Brooklyn							13						15.4		15.4
Mo. No. 65: Columbia			99	76					32.3	10.5					22.9
Kansas station: Manhattan				53	124						22.6	14.5			16.9
Amarillo				38	508						15.8	16.1			16.1
C. I. No. 616: Manhattan						133	81						7.5	17.3	11.2
Giant, Kansas station: Manhattan					117							16.2			16.2
Amarillo					136							25.0			25.0
SUDAN CORN															
Kansas station: Manhattan						152	80						0	0	0
Mo. No. 197: Brooklyn							10							0	0

*Hybrid broomcorn.*—Two hybrids in which broomcorn was one parent were grown at Manhattan in 1919. These hybrids were developed by Samuel J. Weed, of Monmouth, Ill. The parentage of both was the same, namely, Early Amber sorgo and Standard broomcorn. These hybrids have juicy stems but produce brush of only mediocre quality, and they are not yet grown commercially. Both have proved susceptible to the covered kernel smut. One of the hybrids, Amber Saccharine broomcorn (C. I. No. 619), produced 19 infected plants out of a total of 74, or 25.7 per cent. The other hybrid, Golden Saccharine broomcorn (C. I. No. 618), gave 5 infected plants out of a total of 39, or 12.8 per cent.

*Darso.*—Darso was developed at the Oklahoma Agricultural Experiment Station, but its exact origin and history are not known. It may have originated from a cross between a sorgo and a kafir, as it possesses some characteristics of both groups. At the Oklahoma station darso is a dwarf plant about 4 feet tall with a large number of leaves. It has short internodes and is comparatively free from suckering. The heads are rather loose and 10 to 12 inches long; the seeds, which are ovate, somewhat flattened, and of a reddish brown color, do not shatter. The glumes are black and cover about half of the seed when mature.

A strain of darso (Missouri No. 49) was grown at Columbia during 1916, 1917, and 1918. No infected heads were obtained, although a total of 327 plants was grown. It was also grown at Brooklyn, where 12 plants matured, but none was infected. Darso (C. I. No. 615) was grown at Manhattan in 1921, but no smutted plants out of a total of 80 were observed.

The results indicate very clearly that darso is very resistant to the covered kernel smut. It raises the interesting question whether darso has originated from a hybrid between kafir and a sorgo, as has been suggested, as kafirs and sorgos are both susceptible to the covered kernel smut. It would seem more logical to suppose that some resistant sorghum, such as milo, entered into the original cross.

*Freed sorghum.*—Freed sorghum is named for J. K. Freed, of Scott City, Kans., on whose farm it was first grown. Its exact origin is unknown. It is more or less intermediate between some grain sorghum and a sweet sorghum. The stems are only slightly juicy and sweet, and the seeds are not astringent, as are those of most sorgos. The seeds are plumper, somewhat more flattened, chalky white, and not so long as those of the Amber varieties. The glumes are yellowish white and nearly inclose the seed. The plants grow 3½ to 7 feet tall.

One strain of Freed sorghum was grown at Columbia. The results in the two years during which this strain was grown indicate a moderate degree of resistance. A total of 438 plants was grown, of which 23, or 5.3 per cent, were infected. S. P. I. No. 29166 was grown at Amarillo, Tex., during three seasons. Out of a total of 710 plants, 187 (26.3 per cent) were infected. This same strain was grown at Manhattan three seasons with an average infection of 8 per cent. At Rosslyn 4 out of 76 plants were infected. C. I. No. 350 gave negative results at Manhattan, 768 plants having been grown in two years.

*Dwarf hegari.*—Hegari, from which Dwarf hegari was selected, was originally obtained from Khartum, Sudan, Africa. In general appearance Dwarf hegari resembles Dawn kafir to some extent. It

is somewhat intermediate between this kafir and feterita in the compactness of the head and the size and markings of the seed. It stands up well in storms, lodging very little. The stems are stout, 4 to 5 feet tall, fairly juicy, and slightly sweet. The variety promises to be of some value as a forage crop because of the juicy stem. It also has the advantage of erect heads, which renders harvesting less difficult.

Two different strains of Dwarf hegari were grown at Columbia, with a total of 464 plants, all of which were free from smut. One of these strains was grown at Arlington Experiment Farm, 22 normal plants being obtained. S. P. I. No. 34911 was grown at Brooklyn and Manhattan, with no infection taking place. The evidence indicates the presence of marked resistance to covered kernel smut.

*Husserita*.—Husserita is a hybrid developed by H. Willis Smith, formerly of Garden City, Kans. Its ancestry is complicated, but feterita and a sorgho seem to be involved. The head is compact, the grain white, the glumes red to black, and the stalks somewhat juicy. It was grown two years at Manhattan and proved to be somewhat susceptible. Out of 247 plants grown, 14, or 5.7 per cent, were infected.

*Kafirita*.—This sorghum was obtained some years ago by C. V. Piper, of the United States Department of Agriculture, from a farmer at Cedar Hill, Tex. It first appeared in a field of Red kafir. It does not seem to possess any special agronomic value. C. I. No. 548 was grown two years at Manhattan. No smutted plants were obtained out of a total of 177.

*Schrock sorghum*.—Schrock sorghum was developed from a selection made in 1912 by Roy Schrock at Enid, Okla., where he found the original head in a sorghum field along his mail route. It is probably a chance hybrid between a kafir and a sweet sorghum. The plants have stout stems 4½ to 5 feet tall, medium juicy, and rather sweet.

At Columbia two strains were grown in 1917 and 1918. In 183 plants of Missouri No. 38 there were 48 smutted plants, or 26.2 per cent. In 175 plants of Missouri No. 65 there were 40, or 22.9 per cent, infected. A strain was grown at Manhattan and Amarillo for two years, and 16.9 per cent of the plants grown at Manhattan and 16.1 per cent of those grown at Amarillo were smutted. C. I. No. 616 was grown two years at Manhattan, 11.2 per cent of the plants being infected. A so-called Giant Schrock also was grown at Manhattan and Amarillo in 1919. At the former station 16.2 per cent of the plants and at the latter 25 per cent were infected. This probably is a selection which was given a distinct name because of its size.

*Sudan corn*.—Sudan corn was grown for a time by farmers in central and southeastern Kansas, but the acreage is decreasing. It somewhat resembles Standard White milo, but is probably a hybrid. One strain was grown at Manhattan for two years, no infection occurring in a total of 232 heads. Negative results also were obtained at Brooklyn, but only 10 plants matured.

TABLE 9.—*Results of inoculation experiments with head smut of sorghum on various sorghums at the Amarillo Field Station in 1916, 1917, and 1919*

Group and variety	Serial No.	1916		1917		1919	
		Plants	Infection	Plants	Infection	Plants	Infection
		Number	Per cent	Number	Per cent	Number	Per cent
Shallu	C. I. 85	12	0	176	1.7	235	0.4
Sorgos and grass sorghums:							
Black Amber	S. P. I. 32384	83	3.6	173	7.5	1,127	8.9
Black Dwarf	Kansas station					659	.7
Collier	do					514	2.5
Dakota Amber	F. C. I. 1528	74	0				
Folger Early	F. C. I. 1480					720	0
Minnesota Amber	F. C. I. 01950					494	10.5
Early Rose						1,668	10.2
Red Amber	F. C. I. 1534	138	4.3	295	12.8	1,079	27.5
Do	S. P. I. 17548	333	7.4	227	19.3	1,260	26.3
Colman	Kansas station					1,745	16.7
Orange	C. I. 113a					1,062	1.3
Do	F. C. I. 1438	15	0	313	2.2		
Planter	S. P. I. 17539					44	0
Silvertop	Mo. 138					1,720	1.9
Sumac	S. P. I. 35038			231	1.7	1,117	2.5
Honey	F. C. I. 9576					1,216	2.8
Dwarf from Java	S. P. I. 39269					654	3.5
Sudan grass		108	0	137	1.4		
Broomcorn:							
Acme	C. I. 243					1,648	0
Do	C. I. 243-7-2	126	0			845	0
Dwarf	C. I. 442	116	0			871	0
Standard	C. I. 446	121	0	176	0	673	0
Kaoliang:							
Barchet	C. I. 310	21	0	163	.6	901	.1
Mukden	C. I. 190	4	0				
Choonchun	C. I. 413	58	0			528	0
Chusan	C. I. 324	178	0	387	.7	1,011	.6
Manchu	C. I. 171	54	0	221	0	674	.2
Do	C. I. 328-1	93	0	213	0	595	0
Parker	C. I. 424	81	0	215	0	604	0
Shantung Dwarf	C. I. 293	87	0			691	0
Kafir:							
Blackhull	C. I. 71	11	0	142	.7	467	.6
Do	C. I. 204					619	0
Do	C. I. 207	15	0			1,097	.8
Blackhull (African)	C. I. 321	39	0			389	.5
Dawn	C. I. 340	26	0	197	.5	1,412	.5
Sunrise	C. I. 472	25	0			921	1.8
White	C. I. 252	9	0	125	0	334	0
Do	C. I. 314	19	0			671	0
Pink	C. I. 432	32	0	195	0	1,493	.1
Do	Kansas station					236	0
Pale Red (African)	C. I. 316	22	0			737	.1
Red	C. I. 34	37	0	83	0	500	.2
Durra:							
Brown	C. I. 183			34	0	477	3.3
Do	C. I. 246			233	0	649	.1
Do	S. P. I. 17537	7	14.2	263	38.0	623	11.5
White	C. I. 81	14	0			486	0
Do	C. I. 437			228	.4	693	1.1
Do	S. P. I. 14518	1	0				
Do	S. P. I. 14628			486	.2	522	1.7
Do	S. P. I. 17535			331	25.6	1,083	18.4
Do	S. P. I. 38592			133	0	172	1.1
Feterita:							
Feterita	C. I. 182	4	0			921	0
Spur	Texas station 3232					693	0
Milo:							
Standard White	C. I. 352	15	0	425	0	524	0
Dwarf Yellow	C. I. 332	11	0	311	0	680	0
Standard Yellow	C. I. 234	13	0	209	0	511	0
Miscellaneous:							
Freed	S. P. I. 29166	3	0				
Do						1,156	6.0
Giant Schrock						288	12.8
Schrock						1,024	4.1

## INOCULATION EXPERIMENTS WITH HEAD SMUT

In view of the fact that head smut of sorghum, *Sorosporium reilianum* (Kühn) McAlpine, occurs regularly each year at the Amarillo Field Station, it was possible to observe the occurrence of this smut in the sorghum varieties planted in connection with the experiments with *Sphacelotheca sorghi*. Potter (90), as a result of his studies, came to the conclusion that spores present in the soil, surviving from year to year, were largely responsible for this disease and that seed-borne spores were a very minor factor in the prevalence of head smut. His evidence indicates that the soil of the Amarillo Field Station is thoroughly infested with the spores of this smut.

Table 9 presents the infection percentages recorded at Amarillo during three years, 1916, 1917, and 1919. Unfortunately, no distinction between the head smut and covered kernel smut was made in the counts for 1918. Accordingly, the data on head smut for that year are not available.

Table 9 shows that feterita and the milos, which are so markedly resistant to covered kernel smut, also were resistant to the head smut. None of the varieties of broomcorn showed any infection, although all are moderately susceptible to covered kernel smut. The writers are not aware of any record of the occurrence of *Sorosporium reilianum* on broomcorn. Very little head smut was found among the kafirs and kaoliangs, and with two exceptions the durras proved very resistant, while the sorgos as a group were only slightly infected.

The results show that only eight varieties of sorghum gave indications of moderate susceptibility. Black Amber sorgho (S. P. I. No. 32384) was grown three years, a total of 1,383 plants being obtained, of which 117 (8.5 per cent) were infected. Minnesota Amber (F. C. I. No. 01950) in one year gave 52 infected plants (10.5 per cent) out of a total of 494. Early Rose sorgho was grown one year, and 170 (10.2 per cent) out of 1,668 plants were infected. Red Amber sorgho (F. C. I. No. 1534) was grown three years and 1,512 plants obtained, 341 (22.6 per cent) being infected. Red Amber sorgho (S. P. I. No. 17548) was grown three years, and 401 plants (22 per cent) out of a total of 1,820 were infected. Colman sorgho was grown one year, 292 (16.7 per cent) plants out of 1,745 being infected. Brown durra (S. P. I. No. 17537) was grown three years, a total of 893 plants being obtained, of which 173 (19.4 per cent) were infected. White durra (S. P. I. No. 17535) was grown two years, and 285 plants (20.2 per cent) out of a total of 1,414 were infected. Giant Schrock sorghum, grown one season, showed 37 infected plants out of a total of 288, an infection of 12.8 per cent.

All of these varieties are moderately susceptible to the kernel smut (*Sphacelotheca sorghi*). Table 10 presents a summary of the results obtained in infecting these varieties with the two smuts at Amarillo. Brown durra (F. C. I. No. 17537), Minnesota Amber sorgho (F. C. I. No. 01950), and Red Amber sorgho (S. P. I. Nos. 1534 and 17548) appear to be more susceptible to the head smut (*Sorosporium reilianum*). Schrock sorghum, Colman sorgho, and Early Rose sorgho appear to be more susceptible to *Sphacelotheca sorghi*. The other two varieties show no marked differences

TABLE 10.—Comparative susceptibility of certain sorghums to infection with head smut and covered kernel smut at the Amarillo Field Station

Variety	Serial No.	Head smut ( <i>Sorosporium reilianum</i> )			Covered kernel smut ( <i>Sphacelotheca sorghi</i> )		
		Years grown	Heads	Infection	Years grown	Heads	Infection
			Number	Per cent		Number	Per cent
Black Amber sorgo.....	S. P. I. 32384.....	3	1,383	8.4	4	944	8.5
Minnesota Amber sorgo.....	F. C. I. 01950.....	1	494	10.5	1	279	4.6
Early Rose sorgo.....	Mo. 130.....	1	1,668	10.1	1	945	27.1
Red Amber sorgo.....	F. C. I. 1534.....	3	1,512	22.5	4	1,032	9.0
Do.....	S. P. I. 17548.....	3	1,810	22.1	4	1,444	7.4
Colman sorgo.....	Kansas station.....	1	1,745	16.7	2	948	36.1
Brown durra.....	S. P. I. 17537.....	3	893	19.3	4	652	11.3
White durra.....	S. P. I. 17535.....	2	1,414	20.1	4	1,017	18.2
Giant Schrock sorghum.....	.....	1	288	12.8	1	136	25.0

In view of the fact that head smut of sorghum seems to depend for its occurrence primarily upon the spores in the soil, it was not possible to be as certain of results as in the case of the seed-borne covered kernel smut, with which one could be very certain of a thorough inoculation of every seed of each variety and consequently of an equal chance for the infection of the seedlings. Owing to the possible unequal distribution of the spores of head smut in the soil, there may not have been equal opportunities for the infection of the different varieties. However, one is impressed with the fact that head smut as a disease of sorghums appears to be very much less virulent than the covered kernel smut. These results compare very favorably with the records of those who have observed head smut in various parts of the world, although Taubenhaus (108) states that head smut in Texas is almost as destructive as the covered kernel smut.

#### EXPERIMENTS WITH MILO AND FETERITA WITH REFERENCE TO THEIR RESISTANCE TO SPHACELOTHECA SORGHI

The experiments previously described afford ample evidence of the marked resistance of feterita and milo to *Sphacelotheca sorghi* and *Sorosporium reilianum*. A total of 3,638 plants of feterita has been grown at the different stations and only 7 infected plants were observed. As already stated, these infected plants may have been other varieties accidentally present, or they may have been of hybrid origin and because of their smutted condition could not be identified.

Out of a total of 4,529 plants grown at the different stations, no infected plants of Dwarf Yellow milo were observed. No infected plants of Standard Yellow milo were observed in 2,074 plants. A total of 2,256 plants of Standard White milo was grown, and only one infected plant was observed at Columbia, one at Manhattan, and one at Amarillo. Only 144 plants of Dwarf White milo were grown, of which none was infected.

Mention has already been made of the results reported by Kulkarni (64) with Dwarf Yellow milo. Kulkarni was able to obtain three infected heads out of a total of 635, following inoculation with spores of *Sphacelotheca sorghi*. Among the same plants he secured 50 infected with *Sphacelotheca cruenta*, thus indicating the fact that the same lot of seed was inoculated with a mixture of spores of the two smuts. It is not possible fully to explain the differences in the results

obtained by Kulkarni and those of the writers. The three plants infected with *Sphacelotheca sorghi* may have been plants of some other variety; also Dwarf Yellow milo may be somewhat susceptible to *Sphacelotheca cruenta*, although Potter (91) and Reed (97) obtained no infection.

Some preliminary experiments were undertaken to ascertain what factors might be involved in the resistance of milo and feterita. It was thought that the resistance might be chiefly due to varietal differences of a chemical and physiological character. On the other hand, it is possible that certain morphological differences in the germinating seed may account for the consistent absence of smut in these varieties.

The first experiments were conducted in 1916 at Manhattan, Kans., and consisted in the removal of the very thin sheath from the plumule and the application of spores or conidia to the sprouts. It was a difficult matter to remove the sheath without seriously injuring the young plumule. The operation was performed when the plumule of the germinating seed was 2 to 3 millimeters long. After the sheaths were removed the plumules were dusted with spores and with sporidia grown in a carrot decoction, after which the germinating seeds were placed in soil in small flowerpots. The plumules in most instances were unable to emerge through the soil. Instead, they curled up beneath the surface and were unable to break through even the thinnest soil covering. By loosening the soil, however, the young plants were able to emerge, but it was several weeks before the seedlings recovered from the injury. After they were transplanted to the field, they soon became normal in appearance and vigor.

Other experiments were conducted in which the germinating seed was subjected to ether fumes from three to five minutes and then inoculated. After treatment and inoculation, the germinating seeds were planted in flowerpots and transplanted to the field three or four weeks later. Unfortunately, very few of these seeds survived the ether fumes. In those which did survive no smut developed.

The results obtained are presented in Table 11.

TABLE 11.—*Effects of mutilation and etherization of germinating kernels of various sorghums before inoculation with covered kernel smut at Manhattan, Kans., in 1916*

Experiment	Treatment and variety	Number of plants	
		Surviving	Infected
No. 1.....	Plumule sheath removed, dusted with spores:		
	Red Amber sorgo, S. P. I. No. 17548.....	0	-----
	Feterita, C. I. No. 182.....	0	-----
No. 2.....	Standard White milo, C. I. No. 352.....	12	0
	Plumule sheath removed, inoculated with sporidia and spores:		
	Red Amber sorgo, S. P. I. No. 17548.....	2	2
No. 3.....	Feterita, C. I. No. 182.....	3	1
	Standard White milo, C. I. No. 352.....	1	0
	Etherized three minutes, dusted with spores:		
No. 4.....	Red Amber sorgo, S. P. I. No. 17548.....	13	0
	Feterita, C. I. No. 182.....	8	0
	Standard White milo, C. I. No. 352.....	10	0
No. 4.....	Etherized five minutes, dusted with spores:		
	Red Amber sorgo, S. P. I. No. 17548.....	2	0
	Feterita, C. I. No. 182.....	2	0
	Standard White milo, C. I. No. 352.....	4	0

In experiments 1 to 3 (Table 11) 50 seedlings of each lot were originally used, while 25 were used in experiment 4. Red Amber sorgo, which is moderately susceptible to the covered kernel smut, was used as a check.

An examination of Table 11 shows that very few plants grew to maturity. Further, only 3 infected plants were obtained, 2 of Red Amber sorgo and 1 of feterita, both in experiment 2. The head of feterita was only partially smutted, some normal kernels being produced. These were planted in 1917 and typical feterita plants were grown to maturity (Pl. X, fig. 1). There seemed, therefore, to be no question as to the identity of the plant originally infected.

In 1919 another series of experiments involving the removal of the plumule sheath was conducted. The results are shown in Table 12.

TABLE 12.—*Effects of mutilation of germinating kernels of sorghums inoculated with covered kernel smut at Manhattan, Kans., in 1919*

Variety	Serial No.	Seed- lings	Plants infected	Infec- tion
		<i>Number</i>	<i>Number</i>	<i>Per cent</i>
Standard White milo.....	C. I. 352.....	204	0	0
Feterita.....	C. I. 182.....	68	4	5.8
Blackhull kafir.....	C. I. 207.....	1	1	100.0
Red Amber sorgo.....	S. P. I. 17548.....	9	4	44.4

In these experiments, 20 check plants each of milo and feterita, 25 of Blackhull kafir, and 22 of Red Amber sorgo were grown. No infection resulted in milo or feterita, while six (24 per cent) of the plants of Blackhull kafir were infected, and one plant (4.5 per cent) of the Red Amber sorgo showed infection.

In the 1919 experiments the germinating seeds, following inoculation, were planted in sawdust instead of soil. This may have caused some injury to the germinating seeds and the spores on account of the slightly acid condition. The removal of the plumule sheaths from feterita, however, resulted in 5.8 per cent infection, although none of the milo plants became smutted.

It seems evident that the removal of the plumule sheath in feterita increases the chances of infection and that perhaps this structure may act as a protecting factor against smut infection.

The question arises in connection with the sorghum kernel-smut infection whether the rate of germination is a factor in resistant varieties. A preliminary study of the germination of some of the sorghums at various temperatures was conducted in the laboratory to discover whether milo, feterita, and some of the other smut-resistant sorghums germinated more rapidly than those varieties which are susceptible to smut. If this were the case, the freedom from smut in these varieties might be explained on the basis of escape.

#### GERMINATION STUDIES ON VARIOUS SORGHUMS

In 1922 a set of germination studies was made, using 100 seeds of self-pollinated material of each variety. Twenty seeds of each variety were placed in separate Petri dishes, which constituted a series for that variety. Upon the completion of one series a second

was started. This continued until 100 seeds of each variety were germinated at each temperature range. The average growth of each variety in millimeters was thus obtained at the designated temperatures. It is believed these temperatures will closely approach the soil temperatures obtaining at the time when sorghums are generally planted. In the studies made at 19° to 21° C. no striking differences in growth between resistant and susceptible sorghums can be noted. Marked fluctuations, however, within the resistant group itself at these temperatures will be observed. Feterita, for example, germinated more rapidly than the milos. Table 13 shows that the susceptible sorghums as a group at all periods of growth grew about as rapidly as the resistant sorghums. Again it will be seen that feterita at these temperatures grew as rapidly as Red Amber and Black Amber sorgos.

TABLE 13.—*Plumule length of various sorghums at 24-hour intervals when germinated at designated temperatures at Manhattan, Kans., in 1922*

Variety and serial number	Average length of plumules (millimeters)							Smut infection (per cent)	
	Temperature 19° to 21° C.				Temperature 14° to 16° C.			1921	Average <sup>1</sup>
	24 hours	48 hours	72 hours	96 hours	72 hours	96 hours	120 hours		
Black Amber sorgo, S. P. I. No. 32384	0.04	1.18	3.36	7.29	0.40	0.94	1.52	7.4	<sup>2</sup> 16.9
Red Amber sorgo, S. P. I. No. 17548	0	.75	2.17	5.00	.18	.79	1.18	10.5	<sup>2</sup> 12.4
Gooseneck sorgo, Agrost. No. 2652	0	.28	1.35	2.38	0	.07	.55	32.1	<sup>3</sup> 32.1
Blackhull kafir, C. I. No. 207	0	.41	1.70	4.18	0	.22	.78	7.4	<sup>2</sup> 16.2
Sunrise kafir, C. I. No. 4724	0	.69	1.81	3.93	.15	.59	1.05	8.4	<sup>2</sup> 22.8
Dawn kafir, C. I. No. 340	0	.46	1.60	3.01	.01	.29	.96	13.6	<sup>5</sup> 14.3
Progressive kafir, Kansas station	0	.04	.25	.60	0	0	.01	18.2	10.1
Dwarf White milo, Kansas station	0	.48	1.89	4.06	.06	.29	.82	0	0
Standard White milo, C. I. No. 352	.03	.73	2.25	4.33	.02	.50	.93	0	<sup>3</sup> 0
Dwarf Yellow milo, Kansas station	0	.35	1.59	3.27	.02	.13	.48	0	0
Standard Yellow milo, Kansas station	0	.31	1.32	2.99	.08	.30	.87	0	0
Feterita, C. I. No. 182	.17	1.65	3.65	6.34	.17	.97	1.64	0	<sup>2</sup> 0
Spur feterita, C. I. No. 623	.07	1.30	2.65	4.28	.23	.79	1.37	0	0
Darso, C. I. No. 548	0	.29	1.33	3.33	0	.04	.19	0	0
Darso, C. I. No. 615	.05	.83	1.82	4.03	.05	.27	.62	0	<sup>3</sup> 0
Freed sorghum, C. I. No. 350	.21	2.16	4.14	5.78	.74	1.20	1.66	0	0
Dwarf hegari, S. P. I. No. 34911	.05	1.22	2.31	3.94	.46	1.26	1.85	0	<sup>3</sup> 0
Sudan corn, Kansas station	0	1.09	2.45	4.45	.13	.78	1.30	0	0
Husserita, Kansas station	.19	1.65	3.37	5.77	.79	1.40	1.80	7.7	5.6
Shrock sorghum, C. I. No. 616	0	.09	.94	2.21	0	.08	.33	17.3	11.2

<sup>1</sup> Average for two years except as noted.

<sup>2</sup> Average for six years.

<sup>3</sup> One year's data only.

<sup>4</sup> This lot proved to be not Sunrise kafir, but probably was Dawn kafir.

<sup>5</sup> Average for three years.

### INFLUENCE OF EXTERNAL CONDITIONS ON KERNEL-SMUT INFECTION

The sorghum smuts, like the smuts of other cereals, are dependent upon particular environmental conditions, more especially soil temperature and soil moisture. It is well recognized that the amount of smut varies greatly in different seasons, and its prevalence may be more or less correlated with the enviroing conditions at planting time.

Kulkarni (63) has studied the influence of temperature on the germination of sorghum seed and also on the germination of the spores of *Sphacelotheca sorghi* and *S. cruenta*. He found that the

optimum temperature for the germination of the seed was  $36^{\circ}$  to  $40^{\circ}$  C. and that for the spores of the two smuts,  $20^{\circ}$  to  $22^{\circ}$  C. The highest percentages of infection were obtained between  $16^{\circ}$  and  $30^{\circ}$  C.

Kulkarni concludes that the soil temperature and moisture are the determining factors in the occurrence and distribution of the sorghum smuts in the Bombay Presidency. The kharif varieties, sown in the period of higher rainfall and lower temperature, are more severely infected with smut than the rabi sorghums, the latter varieties being sown in the drier, warmer season, when conditions are more favorable for the rapid growth of the seedlings, whose susceptible stage thus is quickly passed over. It also may be noted that the kharif jowar consists mainly of varieties of durra, while the rabi jowar consists of varieties of shallu. Whether the difference in varieties is a factor remains to be determined.

Kulkarni further states that the amount of sorghum smut is very much less in the eastern part of the Bombay Presidency, where there is a decrease in the rainfall and an increase in the temperature, as compared with the western part. The rarity of these smuts in Sind, the Punjab, United Provinces, and Bihar also appears to be dependent upon these factors. Kulkarni attributes special importance to soil temperature in these Provinces, as the average temperature at seeding time is between  $32^{\circ}$  and  $38^{\circ}$  C., which is well above the optimum temperature for the germination of the spores.

In a more recent paper Kulkarni (65) records some experimental data bearing upon the question. He germinated two sets of seed inoculated with spores of *Sphacelotheca sorghi*, one set at  $40^{\circ}$  C. and the second set at  $25^{\circ}$  C. After germination the seedlings were transplanted to pots and the plants grown to maturity. At the higher temperature no infected plants were obtained out of a total of 69, while at the lower temperature 35 out of 64 plants were infected. Two series of field experiments were also carried out, one in 1918 at Pusa, Larkhana, and Poona, and the second in 1920 at Jacobabad and Poona. The temperatures prevailing at the three stations in 1918 during germination were not strikingly different, and fairly high percentages of infection were obtained at each. In 1920 no infection was obtained at Jacobabad, the temperature during the period of germination being  $36^{\circ}$  to  $40^{\circ}$  C., while 65 per cent of infection occurred at Poona, where the temperature during germination was  $25^{\circ}$  C.

As has been previously stated, the preliminary germination studies of susceptible and resistant varieties of sorghum thus far made by the writers (Table 13) do not indicate that any striking correlation exists between the rate of germination and its behavior when subjected to smut infection, but that marked differences in germination can not be noted in the same variety when grown at various temperatures. While it may germinate much more rapidly than other varieties at one temperature, this does not hold for other temperatures. As so little is known about the stage at which infection occurs, it is possible that the periods at which the measurements were made should have been extended so as to obtain greater growth. It seems apparent, however, from the studies thus far made that there is little correlation between the rapidity of early growth and smut resistance or susceptibility. Similar germination studies had been made in 1921, using the same varieties. Only 20

seeds of each variety were used and the temperatures ranged from 27° to 29° and 30° to 32° C. The rate of growth was naturally greater at these temperatures. The same general behavior among the varieties was noted in these experiments as was indicated in Table 13.

If the rate of germination is correlated with varietal resistance, one should be able, perhaps, to produce infection in resistant varieties, like feterita, by reducing the temperature, which in turn would retard the rate of germination. Such conditions undoubtedly occur frequently in nature, but these varieties have maintained their resistance under all conditions in the field.

The percentages of infection obtained at Columbia in 1918 were very much lower than those secured during the two previous years. Plants of certain varieties were grown from the same original lot of seed during 1916, 1917, and 1918. The results are presented in Table 14. It will be noted that the percentages of infection for 1918 are invariably lower than those obtained during 1916 and 1917. In fact, varieties that had been shown by the work of the previous years to be highly susceptible gave very low percentages of infection in 1918 and in a few cases gave negative results. In a number of additional varieties plants were grown from the same seed lot in 1917 and 1918, and the percentages of infection in 1917 were invariably higher than in 1918.

TABLE 14.—*Infection of sorghums with covered kernel smut at Columbia, Mo., in 1916, 1917, and 1918*

Group and variety	Seed serial No.	1916		1917		1918	
		Plants	Infection	Plants	Infection	Plants	Infection
		Number	Per cent	Number	Per cent	Number	Per cent
Shallu.....	46	113	52.2	63	71.4	84	0
Sorgo:							
Collier.....	47	416	19.7	94	23.4	107	1.9
Dakota Amber.....	48	309	16.5	226	21.2	101	0
Minnesota Amber.....	52	193	14.5	103	10.7	137	2.9
Kansas Orange.....	54	253	18.6	113	42.5	56	0
Dwarf Ashburn.....	50	259	28.2	111	37.8	55	0
Broomcorn:							
Standard.....	23	446	24.2	109	31.2	87	1.1
Do.....	24	545	36.3	115	23.5	82	6.1
Do.....	26	321	40.8	120	29.2	68	11.8
Kaoliang:							
Brown.....	40	194	10.8	114	14.0	77	5.2
Manchu.....	39	203	24.6	108	27.8	69	4.3
Kafir:							
Blackhull.....	33	178	53.9	112	68.8	95	7.4
Do.....	34	191	44.5	106	68.9	49	2.0
Red.....	36	318	36.2	100	49.0	47	10.6
Durra:							
Brown.....	30	289	54.0	110	38.2	59	13.6
White.....	32	267	37.1	88	3.4	101	0

The low infection percentages obtained in 1918 perhaps may be correlated with the high temperature and low precipitation during the planting season. Table 15 shows the mean daily temperatures and the total precipitation for the seven days prior to seeding, including the day of seeding, and for the seven days following the seeding of the sorghum.

TABLE 15.—Mean daily temperature and precipitation for seven days preceding and seven days following the seedings of sorghum at Columbia, Mo., in stated years<sup>1</sup>

[T=trace]

Seven-day period	1915			1916			1917			1918		
	Day	Mean tempera- ture	Precipitation	Day	Mean tempera- ture	Precipitation	Day	Mean tempera- ture	Precipitation	Day	Mean tempera- ture	Precipitation
		° F.	In.		° F.	In.		° F.	In.		° F.	In.
Prior to seeding	June 3	71	0	June 16	65	0	June 1	66	0.35	June 4	76	0.10
	June 4	76	0.76	June 11	66	0.03	June 2	60	0	June 5	78	0
	June 5	77	.21	June 12	67	0	June 3	63	0	June 6	76	0
	June 6	76	.01	June 13	70	.01	June 4	73	.09	June 7	68	0
	June 7	58	.47	June 14	70	0	June 5	75	.18	June 8	70	0
	June 8	60	0	June 15	70	.15	June 6	66	0	June 9	74	0
	June 9	60	0	June 16	64	0	June 7	66	T	June 10	79	0
Total or average		68.3	1.55		67.4	.19		67	.62		74.4	.10
After seeding	June 10	72	1.26	June 17	66	0	June 8	69	.28	June 11	82	0
	June 11	71	.36	June 18	71	T	June 9	68	.07	June 12	76	0
	June 12	79	T	June 19	63	T	June 10	68	0	June 13	74	0
	June 13	68	.10	June 20	73	.19	June 11	76	0	June 14	77	T
	June 14	61	.73	June 21	66	0	June 12	80	.17	June 15	84	.17
	June 15	66	0	June 22	78	.04	June 13	66	.20	June 16	88	0
	June 16	72	1.08	June 23	73	.62	June 14	60	0	June 17	88	0
Total or average		69.9	3.52		70	.85		69.6	.72		81.3	.17

<sup>1</sup> The dates of planting were June 9, 1915; June 16, 1916; June 7, 1917; and June 10, 1918.

In general, the infections obtained in 1915 were among the highest, although direct comparison with plants grown from the same seed lot is not possible. During this season the average temperature for the seven days preceding seeding was 68.3° and for the seven days following planting 69.9° F. The precipitation for the first seven days was 1.55 inches, and for the second period of seven days it was 3.52 inches.

The average daily temperature in 1916 for the seven days preceding seeding was 67.4°, and for the seven days following it was 70° F. The precipitation was 0.19 inch for the first period of seven days and 0.85 inch for the second period of seven days. The temperatures for 1917 were practically the same as for 1916, the average for the seven days preceding being 67° and for the seven days following seeding 69.6° F. The precipitation for the first seven days was somewhat lower, 0.62 inch; while for the seven days following it was slightly more, or 0.72 inch. In 1918, however, the average temperature for the seven days preceding seeding was 74.4° F., or about 7 degrees higher than in the preceding two years, and the temperature for the seven days following the seeding was 81.3° F., or more than 10 degrees higher. This higher temperature was associated with extremely low precipitation, there being only 0.1 inch of rain during the seven days preceding and 0.17 inch in the seven days following seeding.

Not only was the precipitation very much less in 1918; it was also differently distributed as compared with the other two seasons. In 1918 the last rain before seeding occurred seven days previously, and there was no rain until five days after seeding except a mere

trace on the fourth day. In 1917, however, rain fell on three different days of the week preceding seeding, and on the day following there was a fall of 0.28 inch. In 1916 most of the rain of the 7-day interval before seeding fell during the preceding 48 hours. After seeding, on the second and third days traces of rain occurred, and on the fourth day 0.19 inch fell.

TABLE 16.—*Climatic data recorded at Columbia, Mo., for the month of May in each year from 1915 to 1918, inclusive*

Year	Temperature (° F.)		Precipitation (inches)	
	Mean	Deficiency or excess	Actual	Deficiency or excess
1915.....	62.6	-1.9	6.32	+1.46
1916.....	64.9	+4	5.21	+35
1917.....	58.6	-5.9	4.89	+3.03
1918.....	68.8	+4.3	3.95	-91

As further evidence bearing upon the question, the month of May, 1918, had a higher mean temperature and lower precipitation than the corresponding months of the other years. The data for this month are presented in Table 16.

TABLE 17.—*Infection of sorghums with covered kernel smut at Manhattan, Kans., in the four years from 1916 to 1919, inclusive*

Variety	Serial No.	1916		1917		1918		1919	
		Plants	Infection	Plants	Infection	Plants	Infection	Plants	Infection
		Number	Per cent	Number	Per cent	Number	Per cent	Number	Per cent
Shallu.....	C. I. 85.....	91	17.6	18	16.7	53	35.8	2	0
Sorgo:									
Black Amber.....	S. P. I. 32384.....	117	27.4	200	21.0	113	40.7	124	13.7
Red Amber.....	S. P. I. 17548.....	382	6.8	148	15.5	125	30.4	123	7.3
Do.....	S. P. I. 1534.....	227	7.9	136	18.4	115	27.8	138	14.5
Broomcorn:									
Acme.....	C. I. 243-7-2.....	176	12.5	150	2.0	64	12.5	92	14.1
Dwarf.....	C. I. 442.....	145	7.6	153	5.2	54	18.5	74	8.1
Standard.....	C. I. 446.....	144	11.1	140	10.0	137	12.4	78	9.0
Kaoliang:									
Brown.....	C. I. 324.....	127	3.9	190	7.9	53	13.2	115	2.6
Do.....	C. I. 413.....	124	3.2	127	0	50	0	104	1.9
Do.....	C. I. 424.....	154	3.2	188	2.1	48	6.3	67	6.0
Manchu.....	C. I. 171.....	110	7.3	125	12.8	99	13.1	103	30.1
Do.....	C. I. 328-1.....	136	6.6	55	18.2	103	28.2	103	37.9
Kafir:									
Blackhull.....	C. I. 71.....	136	7.4	213	2.8	51	43.1	80	25.0
Do.....	C. I. 207.....	95	12.6	97	9.3	59	23.7	151	30.5
Blackhull (African). Dawn.....	C. I. 321.....	104	14.4	163	14.7	131	22.9	67	64.2
Sunrise.....	C. I. 340.....	157	13.4	12	8.3	48	27.1	111	18.0
White.....	C. I. 472.....	137	6.6	50	6.0	107	39.3	125	36.0
White African.....	C. I. 252.....	74	12.2	85	15.3	65	33.8	64	42.2
Pale Red.....	C. I. 314.....	113	14.2	103	25.2	140	18.6	112	28.6
Pink.....	C. I. 316.....	95	14.7	173	28.9	26	42.3	141	38.3
Red.....	C. I. 432.....	105	12.4	8	37.5	101	44.6	113	59.3
Durra:									
Brown.....	C. I. 34.....	107	16.8	175	9.1	135	23.0	121	39.7
Do.....	C. I. 183.....	32	18.8	127	7.1	148	8.8	68	25.0
Do.....	C. I. 246.....	38	36.8	86	12.8	100	48.0	69	33.3
White.....	S. P. I. 17537.....	147	13.6	165	4.8	43	30.2	73	8.2
Do.....	C. I. 81.....	74	14.9	165	10.3	48	25.0	34	52.9
Do.....	S. P. I. 17535.....	153	27.5	76	3.9	84	33.3	96	14.6
Do.....	S. P. I. 28995.....	63	9.5	60	0	116	1.7	101	2.0
Do.....	S. P. I. 38592.....	54	13.0	18	16.7	56	16.1	68	4.4

In contrast with the results obtained at Columbia the percentages of infection noted at Manhattan and Amarillo during the four years from 1916 to 1919 showed no such seasonal variation. The varieties responded somewhat differently in the different years, but no one season stands out markedly as one of exceptionally low or high smut infection. An examination of the mean temperature preceding and following the seeding dates, as well as the precipitation for the corresponding period, likewise reveals no such marked differences in the seasons. The data recorded at Manhattan are presented for comparison in Tables 17 and 18.

TABLE 18.—Mean daily temperature and precipitation for seven days preceding and seven days following the seedings of sorghum at Manhattan, Kans., in stated years<sup>1</sup>

[T=trace]

Seven-day period	1916			1917			1918			1919		
	Day	Mean tempera- ture	Precipitation	Day	Mean tempera- ture	Precipitation	Day	Mean tempera- ture	Precipitation	Day	Mean tempera- ture	Precipitation
		°F.	In.		°F.	In.		°F.	In.		°F.	In.
Prior to seeding.....	May 11	60.0	0	May 18	74.5	0	May 11	55.5	0	May 16	60.0	0.22
	May 12	53.5	1.75	May 19	76.5	0	May 12	61.0	.02	May 17	55.0	0
	May 13	60.5	.10	May 20	68.5	.95	May 13	58.5	0	May 18	60.0	0
	May 14	64.5	1.67	May 21	58.0	.38	May 14	69.5	0	May 19	61.5	.48
	May 15	52.0	0	May 22	57.5	0	May 15	70.5	0	May 20	56.0	0
	May 16	55.5	0	May 23	49.5	0	May 16	75.0	0	May 21	56.5	0
	May 17	56.0	0	May 24	56.0	0	May 17	76.0	0	May 22	60.0	0
Total or average	-----	57.4	3.52	-----	62.9	1.33	-----	66.6	.02	-----	58.4	.70
After seeding.....	May 18	59.0	0	May 25	59.0	0.35	May 18	74.0	0	May 23	64.0	0
	May 19	61.5	T	May 26	61.5	0	May 19	80.0	0	May 24	70.0	0
	May 20	63.0	.70	May 27	56.0	.25	May 20	70.0	0	May 25	68.0	T
	May 21	65.5	.69	May 28	59.5	0	May 21	80.0	1.11	May 26	71.0	.71
	May 22	66.0	T	May 29	64.5	.24	May 22	76.5	2.15	May 27	68.0	.72
	May 23	70.0	.37	May 30	64.0	1.29	May 23	60.5	.10	May 28	71.0	.95
	May 24	79.5	0	May 31	63.0	0	May 24	76.5	0	May 29	74.0	0
Total or average	-----	66.4	1.76	-----	61.1	2.13	-----	73.9	3.36	-----	69.4	1.48

<sup>1</sup> The dates of planting were as follows: May 17 and 18, 1916; May 24 and 25, 1917; May 16 and 17, 1918; and May 22, 1919.

## GENERAL CONCLUSIONS

Ten species of smuts have been recorded on sorghum (*Holcus sorghum* L.) and the related Johnson grass (*Holcus halepensis* L.). Seven of these species appear to be very local in their distribution: *Tolyposporium filiferum* Busse in Tanganyika Territory, Egypt, Mesopotamia, and India; *T. volkensis* P. Henn. in Tanganyika Territory; *Ustilago bulgarica* Bubák in Bulgaria; *Ustilago sorghicola* Speg., near La Plata, Argentina; *Sorosporium ehrenbergii* Kühn, in Cairo, Egypt; and *Endothlaspiis sorghi* Sorok., in central Asia. *Ustilago sorghicola* and *Endothlaspiis sorghi* are probably identical with *Sphacelotheca sorghi* (Link) Clinton. The description of *Sorosporium ehrenbergii* agrees fairly well with *Sorosporium reilianum* (Kühn) McAlpine, but the specimen issued in De Thümen Mycotheca Universalis No. 725 is certainly *Sphacelotheca sorghi* (Link) Clinton. *Sorosporium simii* Evans has been described on *Holcus halepensis* from

Natal, South Africa. It, however, probably is identical with *Sorosporium reilianum* (Kühn) McAlpine.

The remaining three species are widely distributed in the sorghum-growing areas of the world. *Sphacelotheca sorghi* (Link) Clinton is coextensive with the cultivation of sorghum. It is the most destructive disease of this crop, annually causing heavy losses in China, India, Africa, and the United States. *Sphacelotheca cruenta* (Kühn) Potter appears to be less widely distributed, perhaps in part because it has been confused with the preceding species. *Sorosporium reilianum* (Kühn) McAlpine is especially interesting because it occurs on both sorghum and maize. It causes some loss to sorghum in certain parts of India and in the Great Plains area of the United States. It is destructive to maize in Australia, South Africa, and in certain parts of India. It has been reported as an important disease of this crop in Washington, and it occurs in California.

The present investigations were undertaken primarily to determine the varietal resistance of sorghums to covered kernel smut (*Sphacelotheca sorghi* (Link) Clinton). The experiments were conducted at the following stations: Columbia, Mo. (four years, 1915 to 1918); Manhattan, Kans. (six years, 1916 to 1921); Amarillo, Tex. (four years, 1916 to 1919); Arlington Experiment Farm, Rosslyn, Va. (one year, 1920); and Brooklyn, N. Y. (one year, 1921). Observations also were made on the behavior toward *Sorosporium reilianum* (Kühn) McAlpine of the sorghum varieties grown at Amarillo.

In the course of the experiments with covered kernel smut, varieties of all the different groups of sorghums, including practically all of agronomic importance, have been grown. Many of the varieties have been represented by several different strains obtained from various sources. A few sorghums, mostly hybrids not definitely referable to any of the recognized groups, also have been grown. The results may be summarized as follows:

- (1) All the strains of shallu proved to be very susceptible.
- (2) As a group, the sorgos were found to be susceptible and generally had high percentages of infection.
- (3) Sudan grass appears to be only moderately susceptible.
- (4) The three varieties of broomcorn have proved to be moderately susceptible to covered kernel smut. The highest percentages of infection obtained were as follows: Acme, 37.2 per cent, at Brooklyn; Dwarf, 20.4 per cent, at Amarillo; and Standard, 40.8 per cent, at Columbia. A strain of Standard, Missouri No. 198, showed 45.5 per cent infection, but only 11 plants matured, so that the numbers are not large enough to be very significant.
- (5) Shantung, a dwarf brown kaoliang, has proved very resistant, as only two plants out of a total of 1,845 were infected, and there is some question as to the identity of these. Most of the Brown kaoliangs showed low percentages of infection except at Brooklyn. Barchet, Blackhull, Manchu, and Mukden White are susceptible varieties.
- (6) The kafirs have all proved to be very susceptible.
- (7) The two varieties of durra, Brown and White, which have been grown in the United States for several years, have proved to be very susceptible. Some recent introductions of White durra have shown a high degree of resistance.
- (8) The four varieties of milo have shown very marked resistance. A total of 4,529 plants of Dwarf Yellow milo, 2,074 of Standard Yellow milo, and 144 of Dwarf White milo were grown, and no infected plants were observed. Three infected plants of Standard White milo out of a total of 2,256 were observed. It is possible that at least two of these infected plants belong to some other variety of sorghum. There can be no doubt, however, as to the identity of the infected Standard White milo plant observed at Amarillo.
- (9) Feterita has proved to be very resistant. A total of 3,638 plants has been grown at the different stations and only 7 have been infected. Some of these may not have been pure feterita.

(10) Among the miscellaneous sorghums some have proved to be very susceptible, such as the hybrid broomcorns and Schrock sorghum. Freed sorghum and husserrita have shown a somewhat lower percentage of infection. Others have shown a high degree of resistance, such as darso, Dwarf hegari, and Sudan corn.

The observations at Amarillo indicate that the sorghums are less susceptible to *Sorosporium reilianum* than to *Sphacelotheca sorghi*. Feterita, milo, and broomcorn have shown no infection. The kafirs and kaoliangs were only slightly infected. The following varieties of sorghum showed marked susceptibility: Brown durra (S. P. I. No. 17537); White durra (S. P. I. No. 17535), Black Amber sorgo (S. P. I. No. 32384), Minnesota Ambersorgo (F. C. I. No. 01950), Red Ambersorgo (S. P. I. Nos. 1534 and 17548), Colman sorgo, Early Rosesorgo, and Schrock sorghum.

By removing the plumule sheath from germinating seeds and inoculating them with spores of *Sphacelotheca sorghi* it was possible to secure heads of feterita infected with kernel smut. This method was not successful with milo.

There appears to be no correlation between the rate of germination of sorghums and their susceptibility to infection with covered kernel smut (*Sphacelotheca sorghi* (Link) Clinton).

Environmental conditions play an important part in the percentage of infection with covered kernel smut. The results in 1918 at Columbia, Mo., were markedly lower than those obtained in previous years. These low percentages of infection perhaps may be correlated with the high temperature and low precipitation preceding and following the planting of the grain. No such marked differences in the percentage of smut infection were observed at the Manhattan station, where the environmental conditions were not strikingly different during the various planting seasons.

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